US009318812B2

(12) **United States Patent**
McCarville et al.

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(45) **Date of Patent: Apr. 19, 2016**

(54) **ANTENNA FABRICATION**

(71) Applicant: **The Boeing Company**, Chicago, IL (US)

(72) Inventors: **Douglas A. McCarville**, Bonney Lake, WA (US); **Joseph A. Marshall, IV**, Lake Forest Park, WA (US); **Manny S. Urcia**, Bellevue, WA (US); **Otis F. Layton**, Bonney Lake, WA (US)

(73) Assignee: **THE BOEING COMPANY**, Chicago, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 434 days.

(21) Appl. No.: **13/866,310**

(22) Filed: **Apr. 19, 2013**

(65) **Prior Publication Data**

US 2013/0229321 A1 Sep. 5, 2013

Related U.S. Application Data

(62) Division of application No. 12/693,672, filed on Jan. 26, 2010, now Pat. No. 8,446,330.

(51) **Int. Cl.**
H01Q 21/26 (2006.01)
H01Q 21/00 (2006.01)
H01Q 21/06 (2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 21/26*** (2013.01); ***H01Q 21/0087*** (2013.01); ***H01Q 21/064*** (2013.01); *Y10T 29/49002* (2015.01); *Y10T 29/49016* (2015.01)

(58) **Field of Classification Search**
CPC .. H01Q 21/26; H01Q 21/064; H01Q 21/0087
USPC 343/767, 770, 893, 708, 797
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,184,141	A	2/1993	Connolly et al.
7,046,209	B1	5/2006	McCarville et al.
7,109,942	B2	9/2006	McCarville et al.
7,109,943	B2	9/2006	McCarville et al.
7,113,142	B2	9/2006	McCarville et al.
7,291,815	B2	11/2007	Hubert et al.
7,580,003	B1	8/2009	Davis et al.
8,446,330	B1	5/2013	McCarville et al.

OTHER PUBLICATIONS

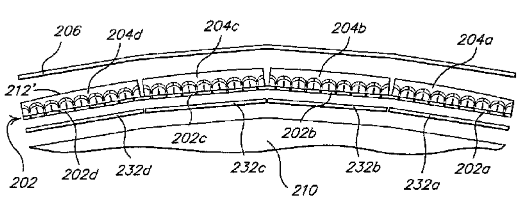
McCarville et al., "Antenna Fabrication," U.S. Appl. No. 12/693,672, filed Jan. 26, 2010, 88 pages.
Non-final office action dated Sep. 11, 2012 regarding U.S. Appl. No. 12/693,672, 8 pages.
Notice of allowance dated Jan. 9, 2013 regarding U.S. Appl. No. 12/693,672, 7 pages.

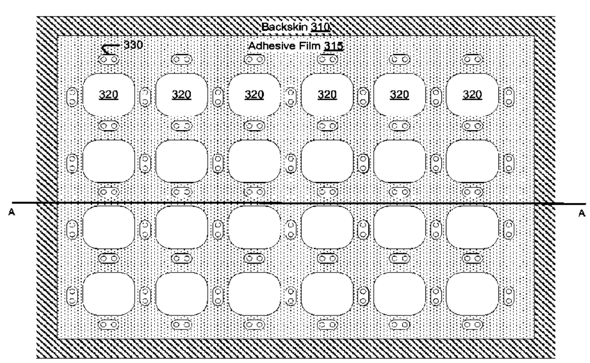
Primary Examiner — Dieu H Duong
(74) *Attorney, Agent, or Firm* — Yee & Associates, P.C.

(57) **ABSTRACT**

In one embodiment a method to form a load bearing antenna aperture comprises forming a honeycomb core structure having a plurality of wall sections, the wall sections including electromagnetic radiating elements, and wherein lower surfaces of the wall sections defines a first surface and upper surfaces of the wall sections define a second surface, positioning a back skin to the first surface of the honeycomb core structure with an adhesive layer which comprises a layer of adhesive film and a paste adhesive disposed on the layer of adhesive film. Other embodiments are disclosed.

19 Claims, 33 Drawing Sheets





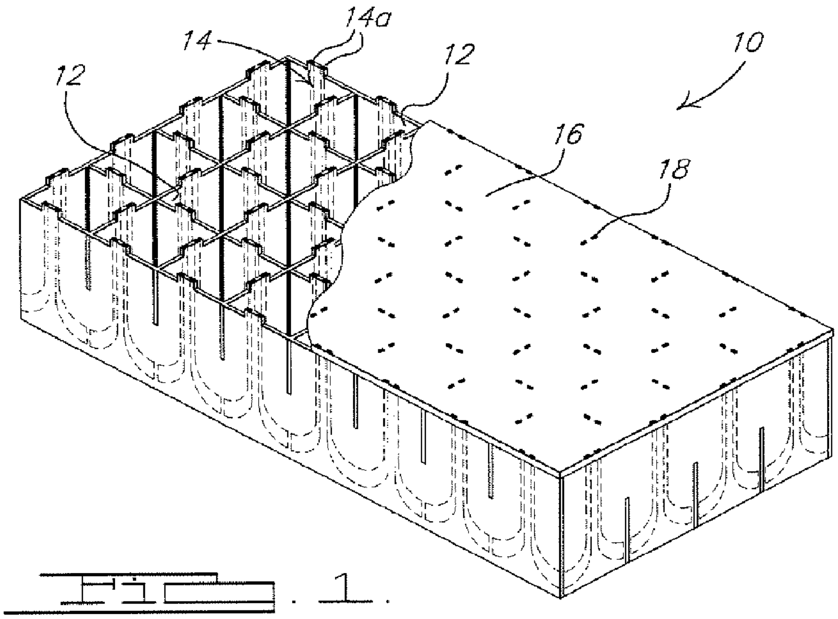


FIG. 1.

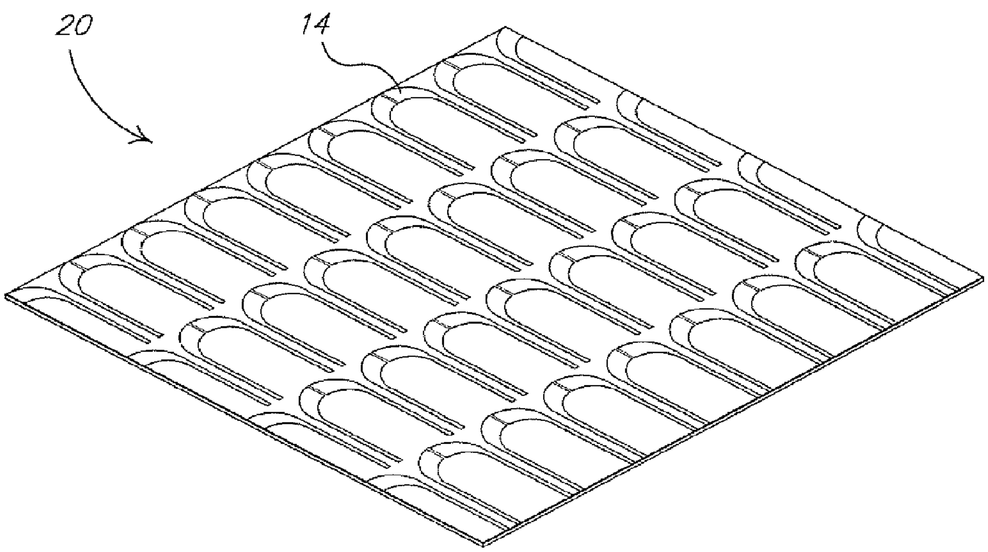
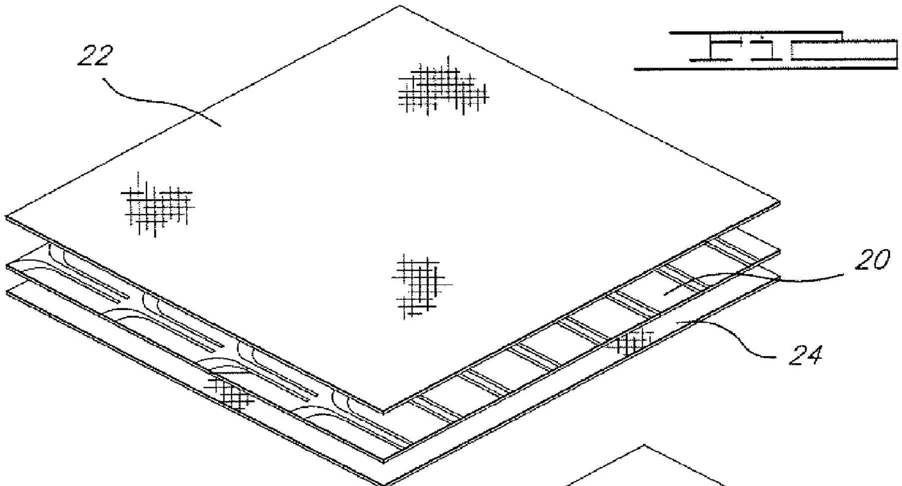


FIG. 2.



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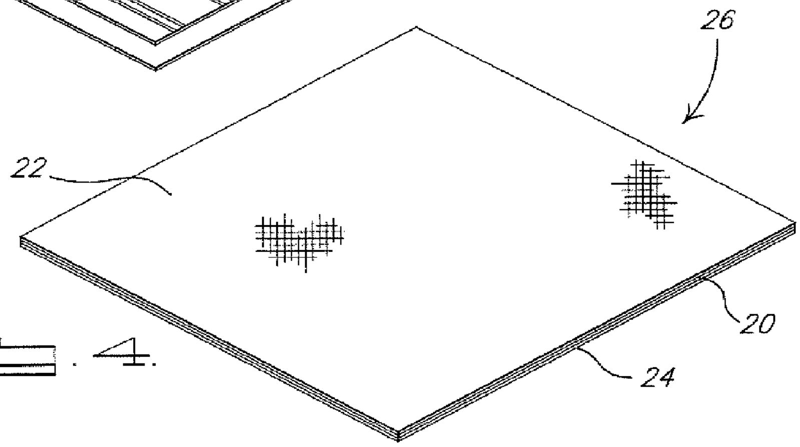

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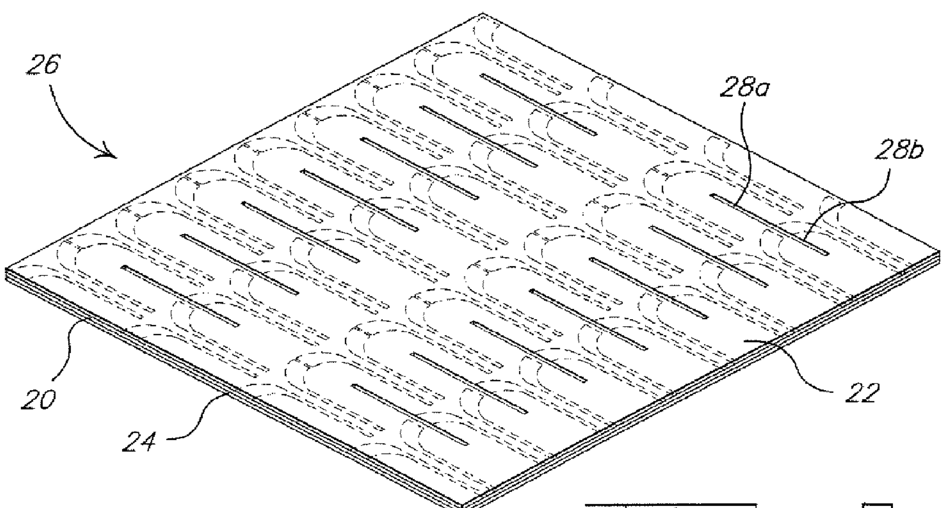

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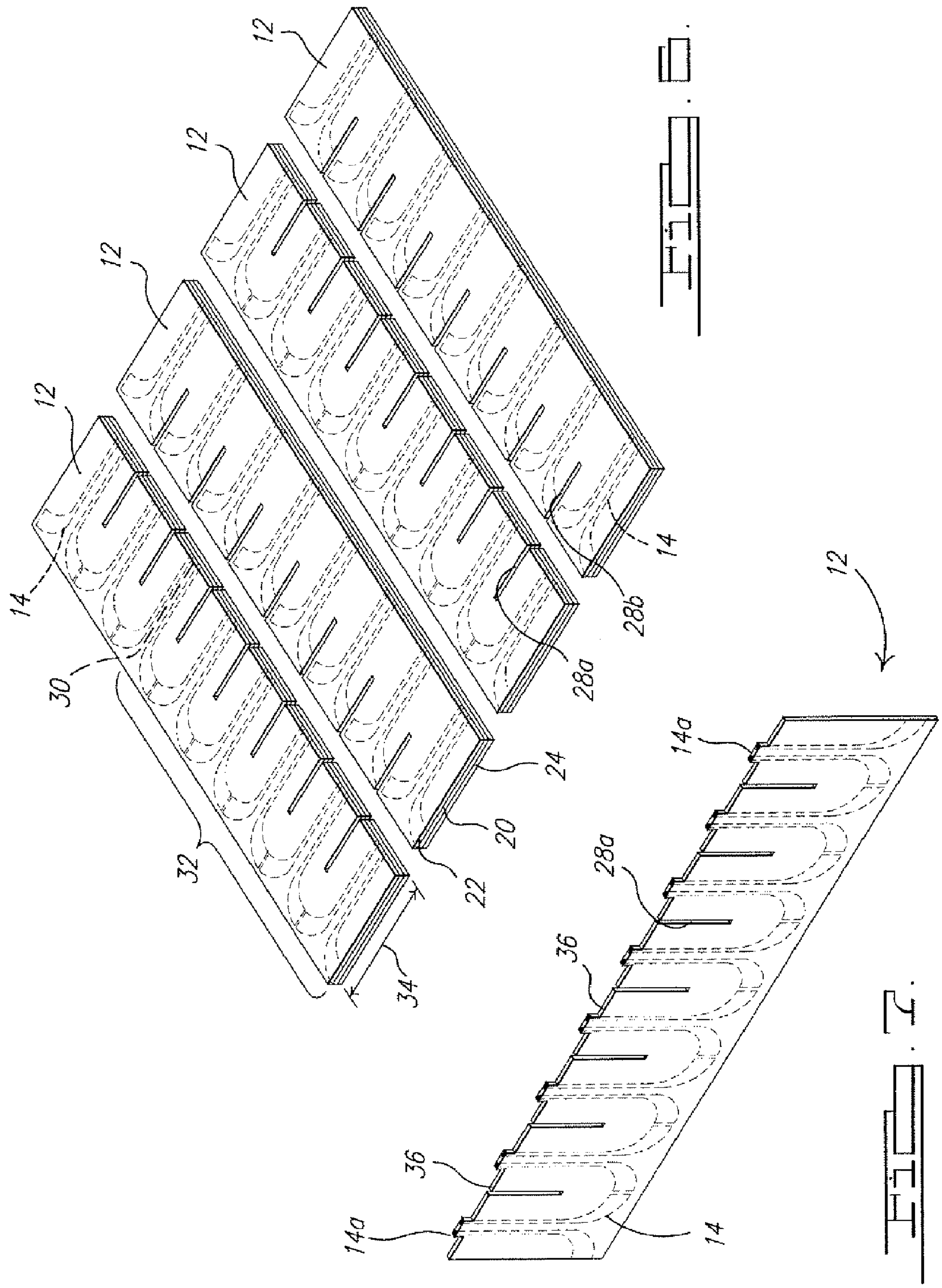
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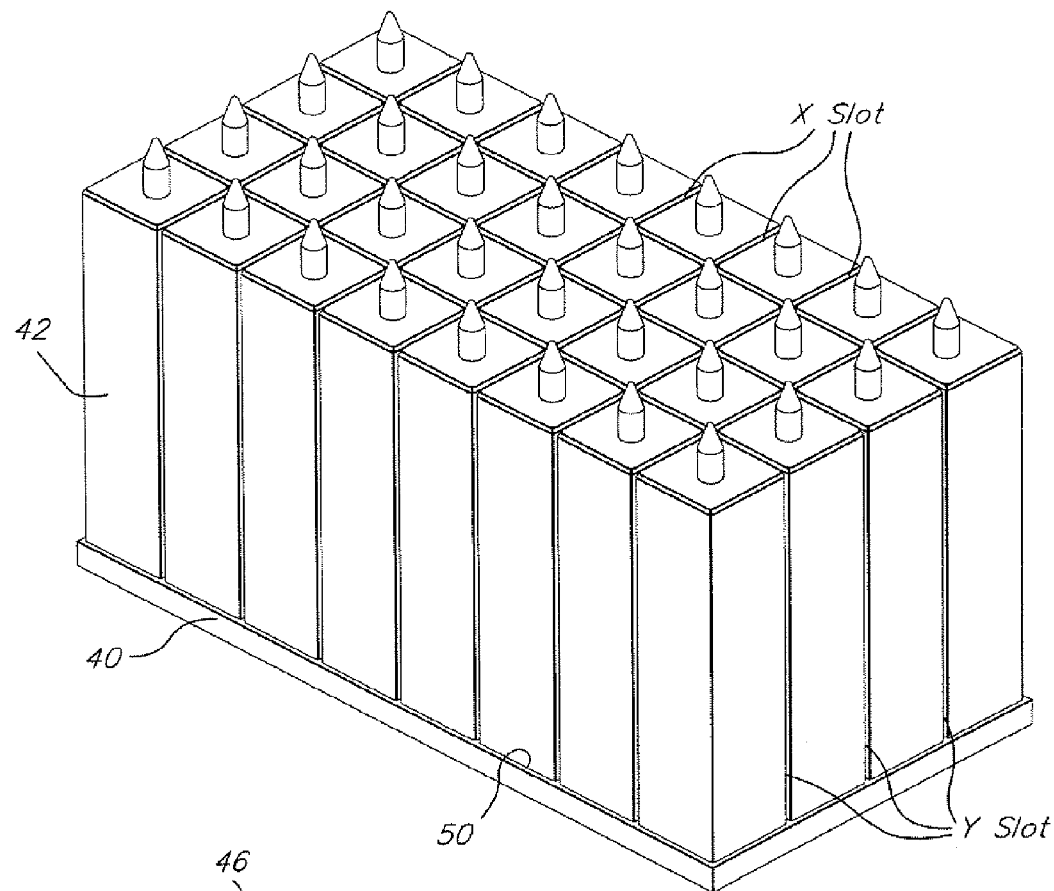

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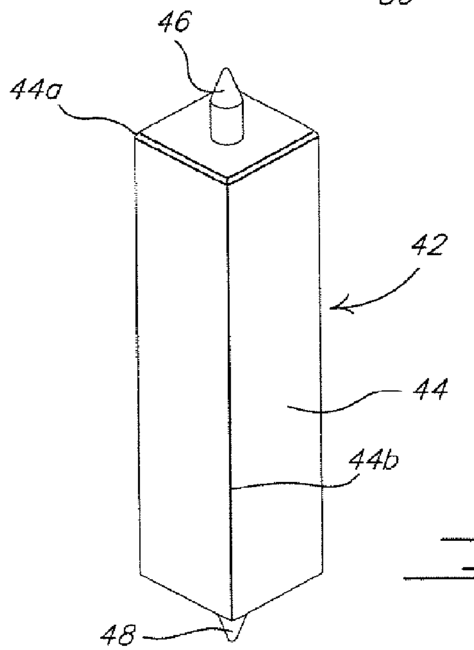

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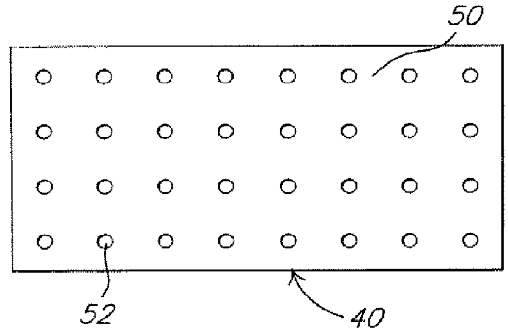

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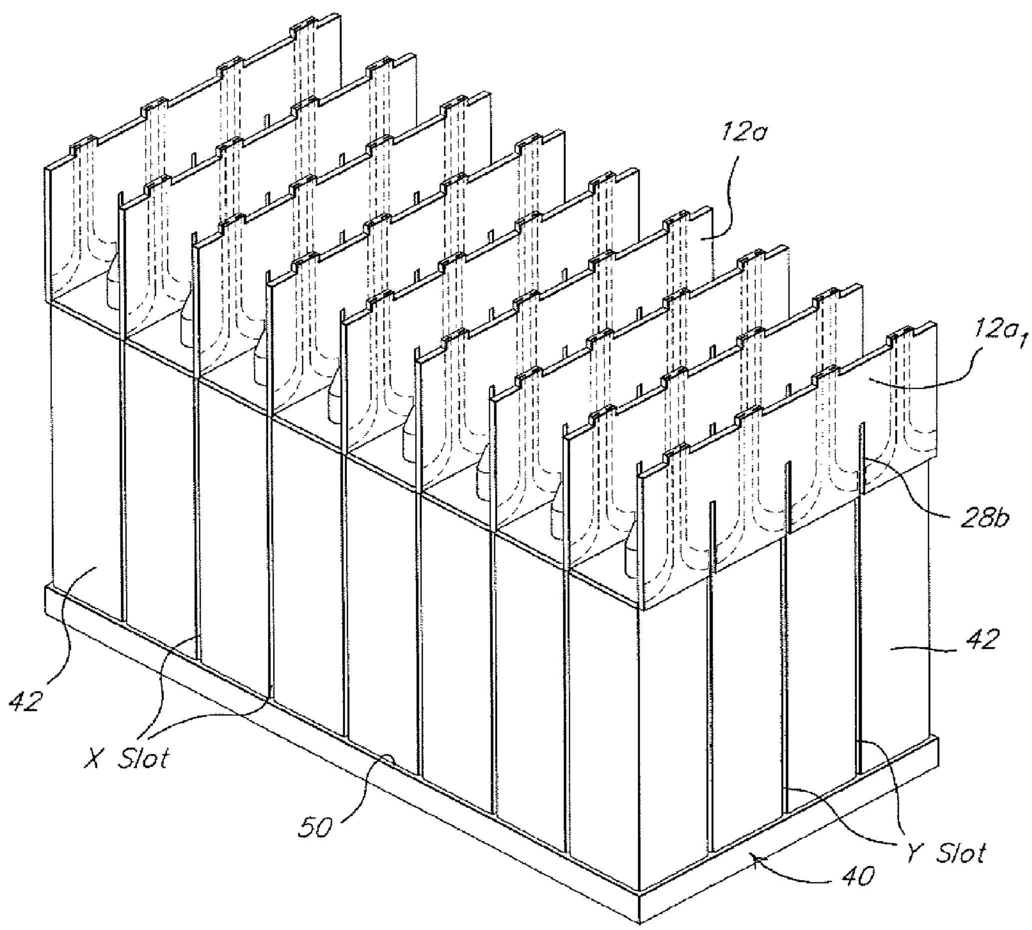
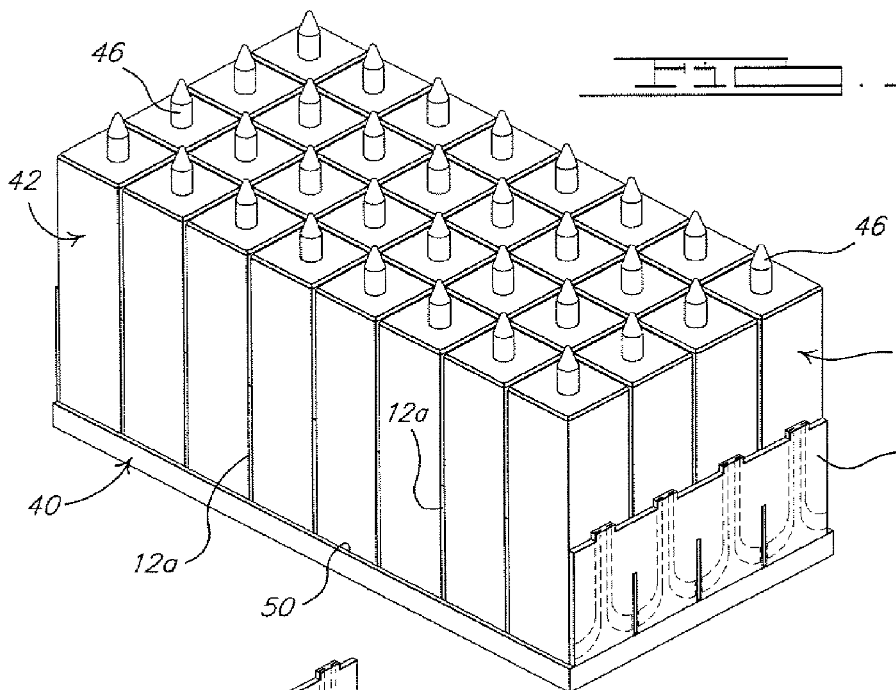
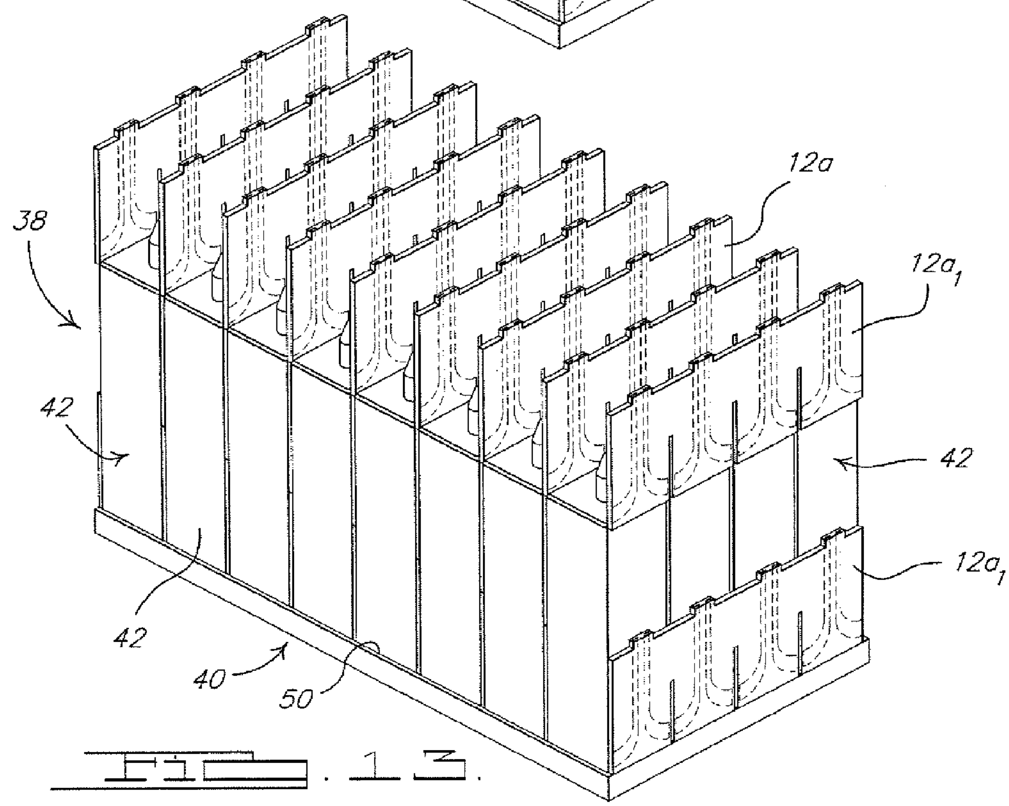


FIG. 11.

FIG. 12.





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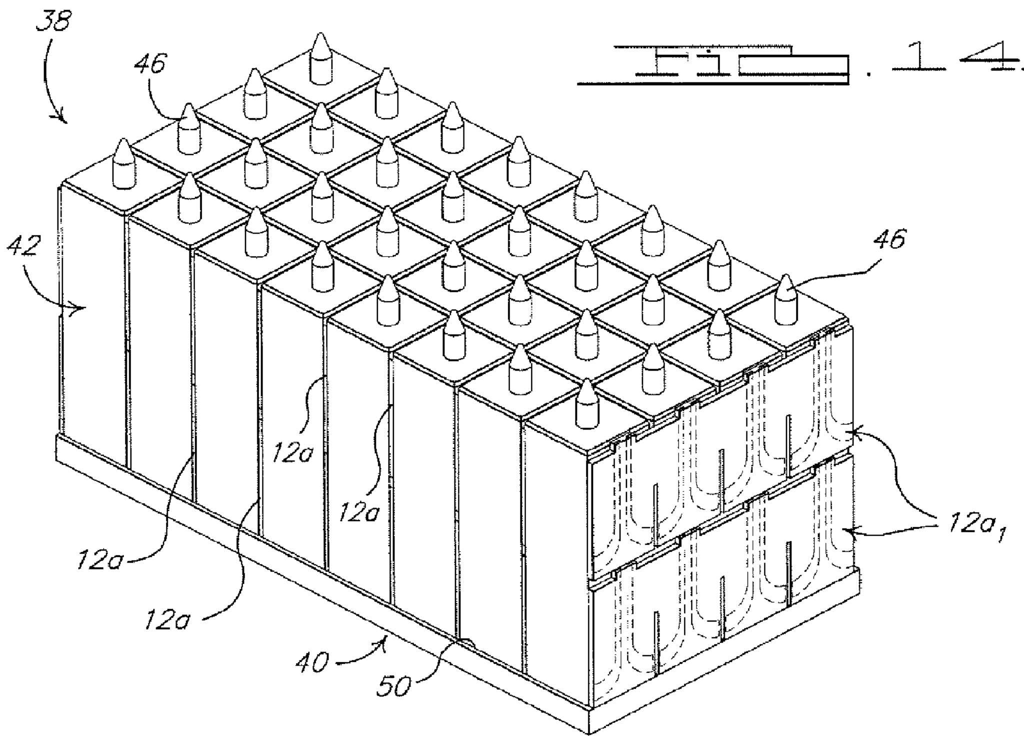
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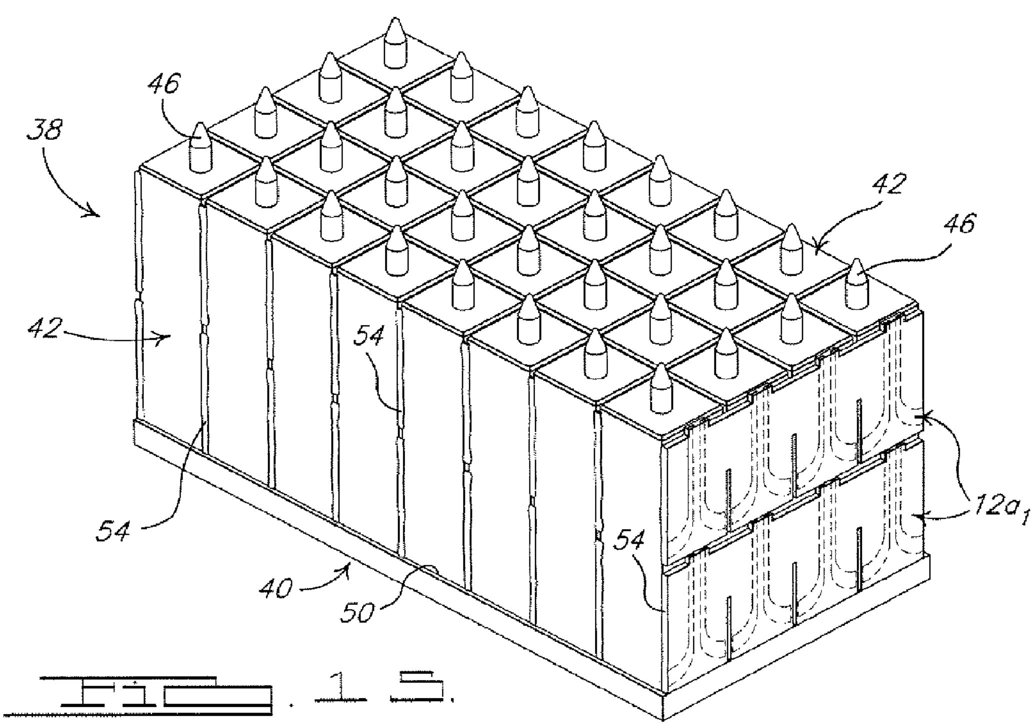
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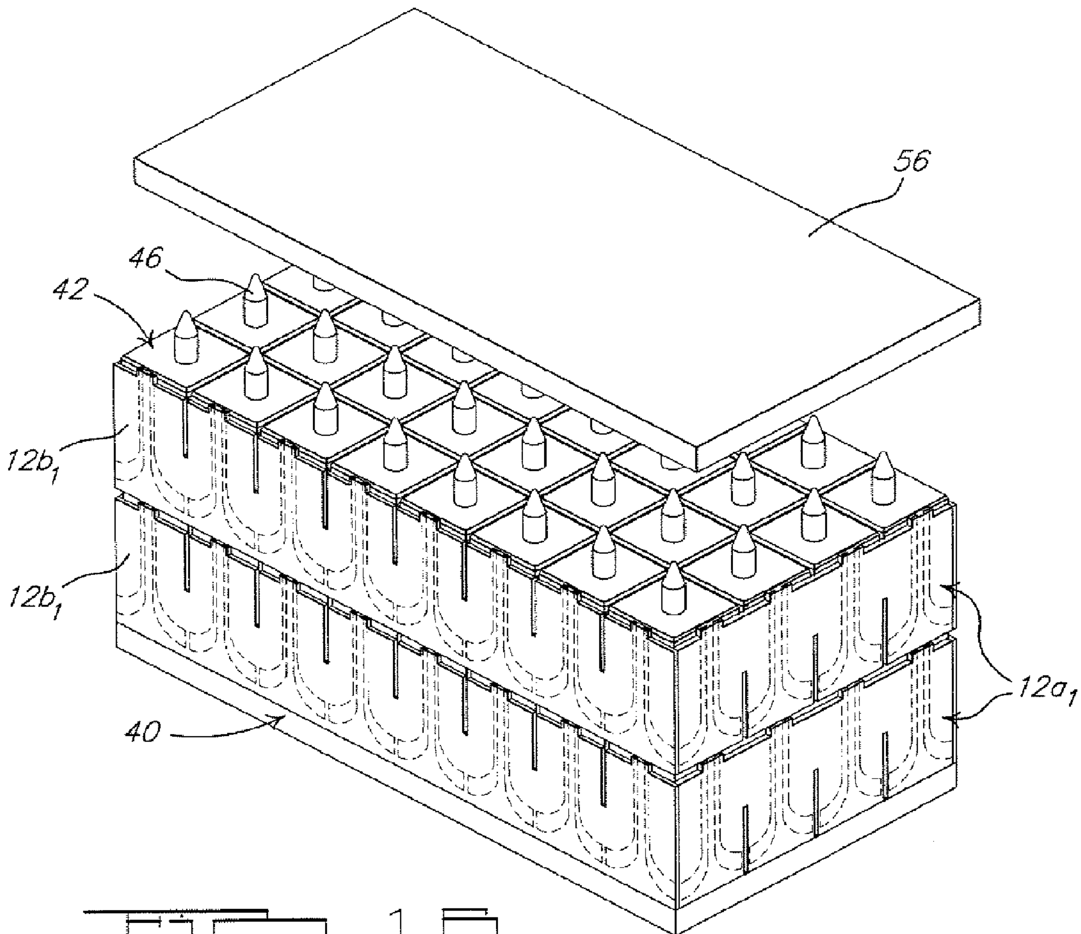

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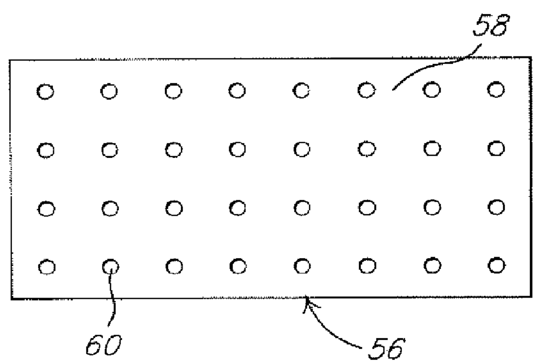

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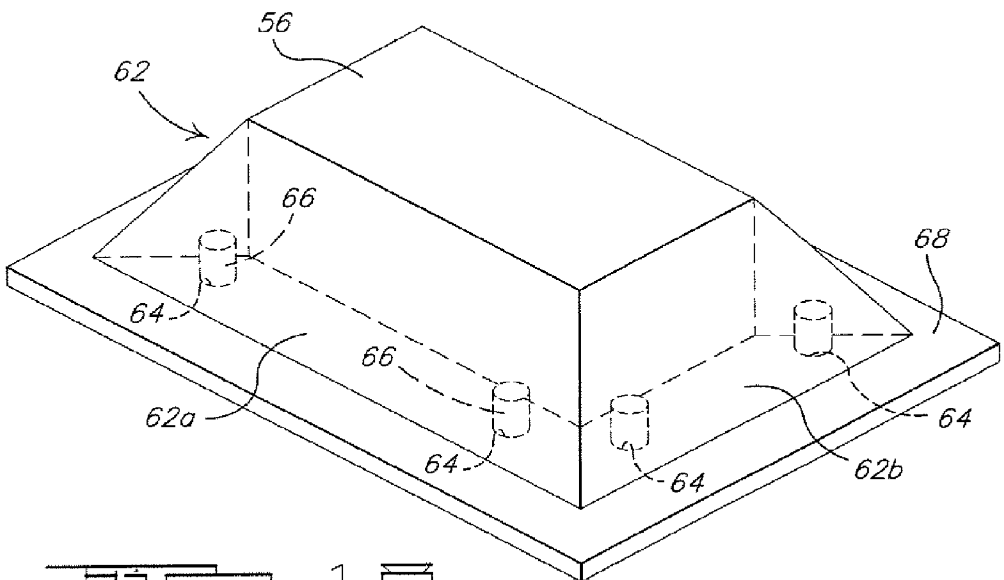

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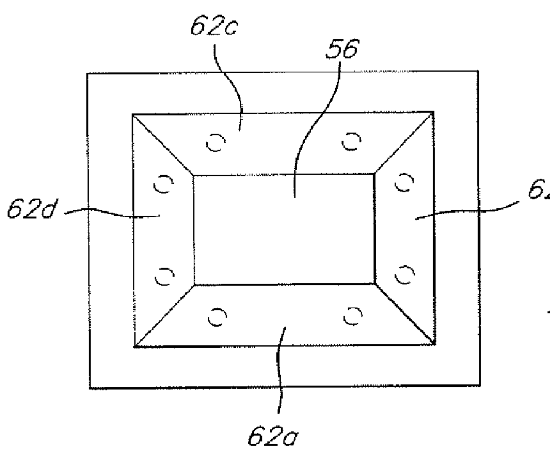

FIG. 19.

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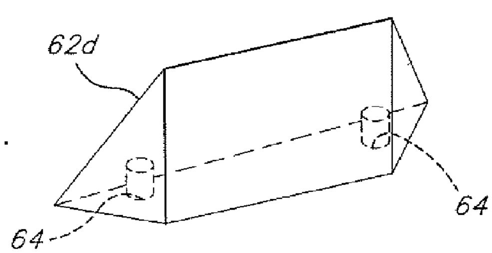

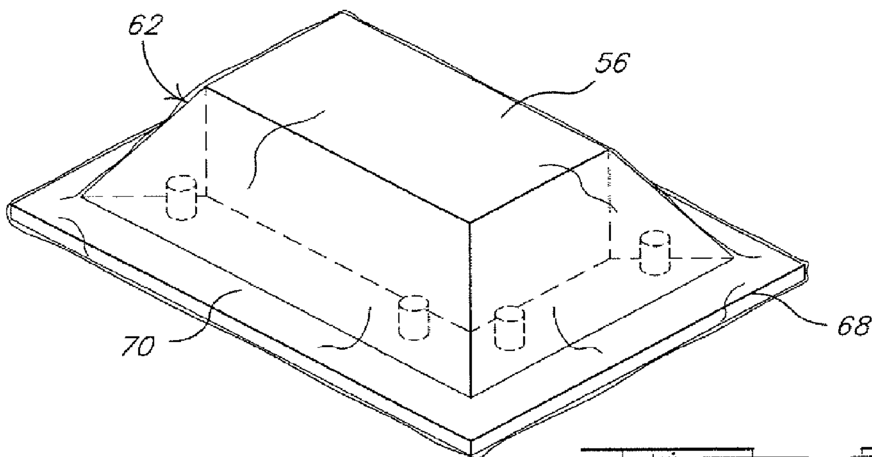
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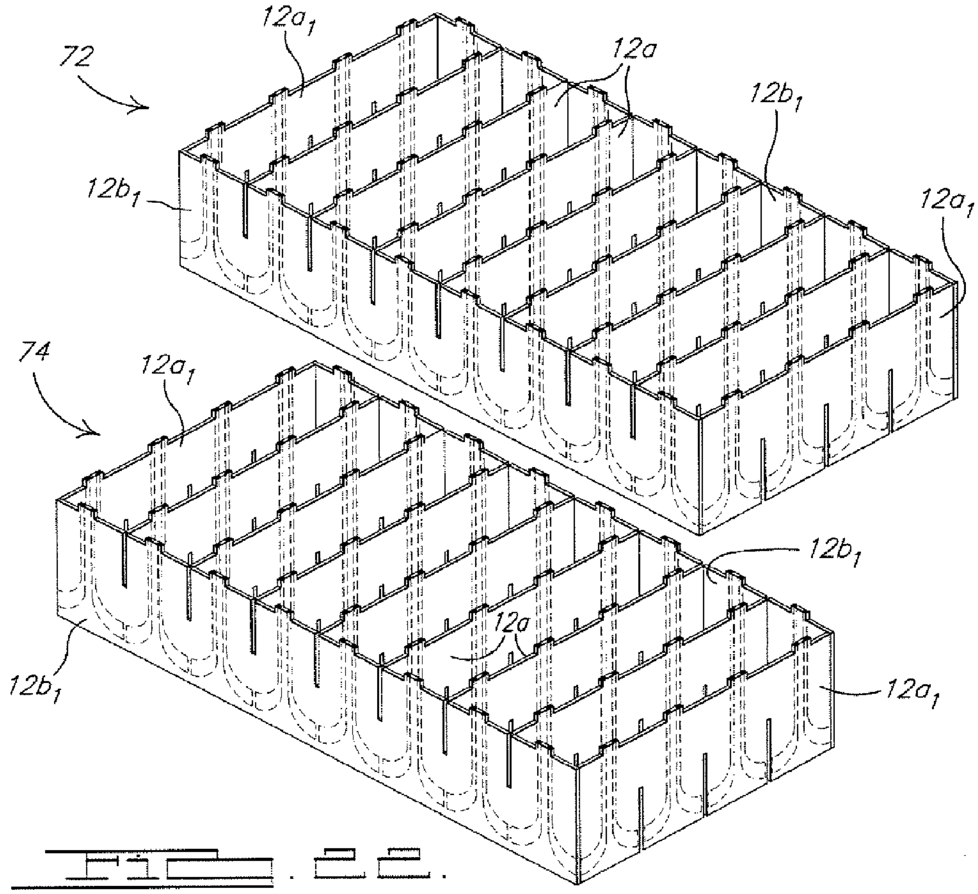
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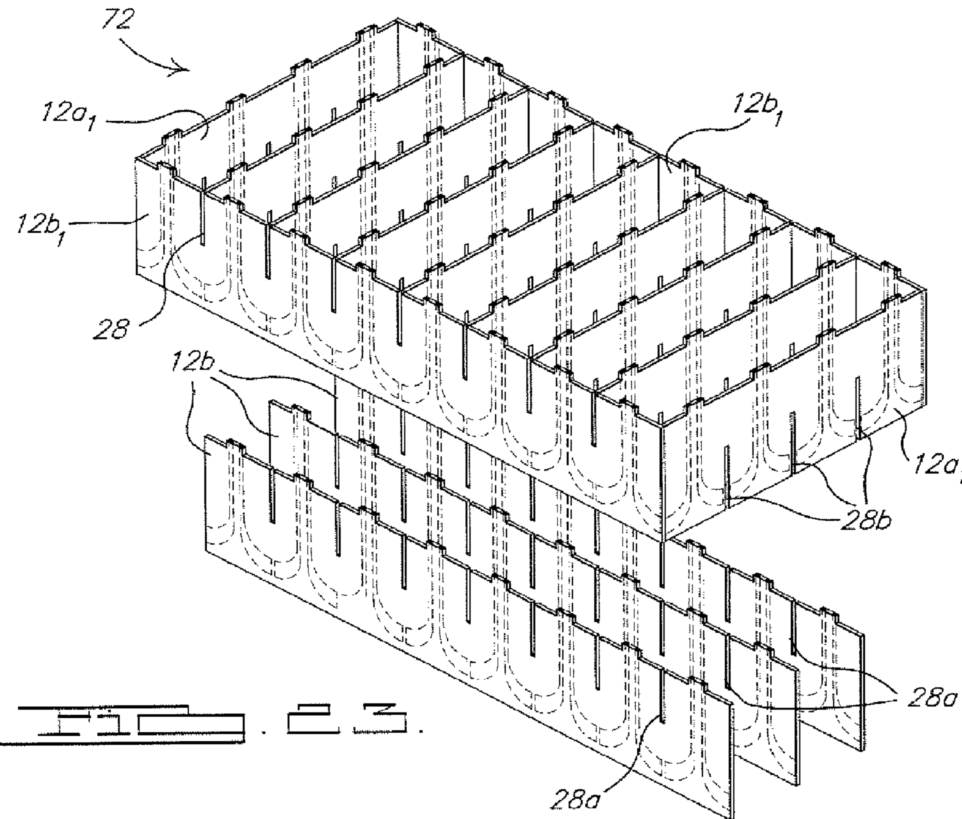
FIG. 22.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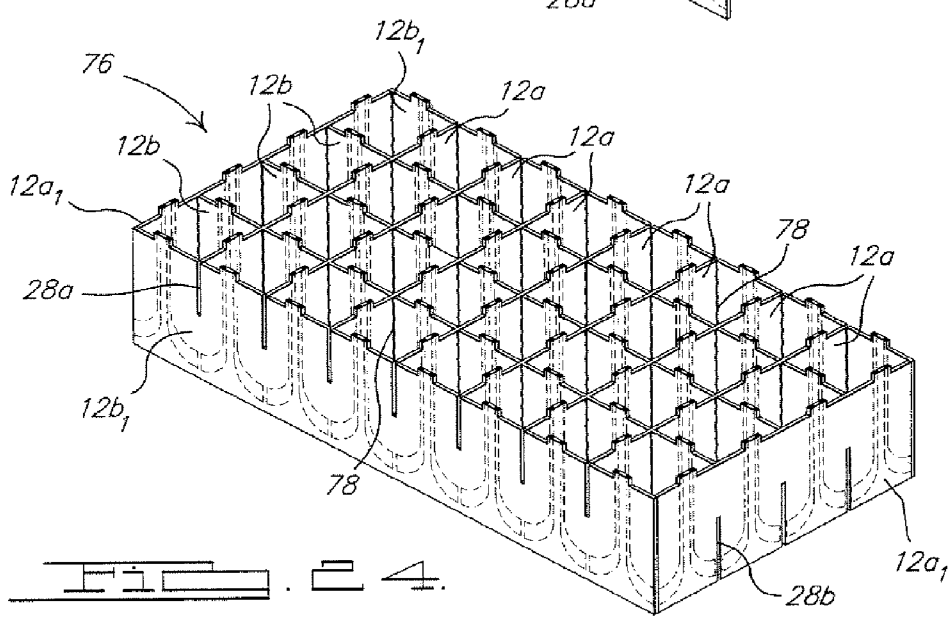
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FIG. 24.

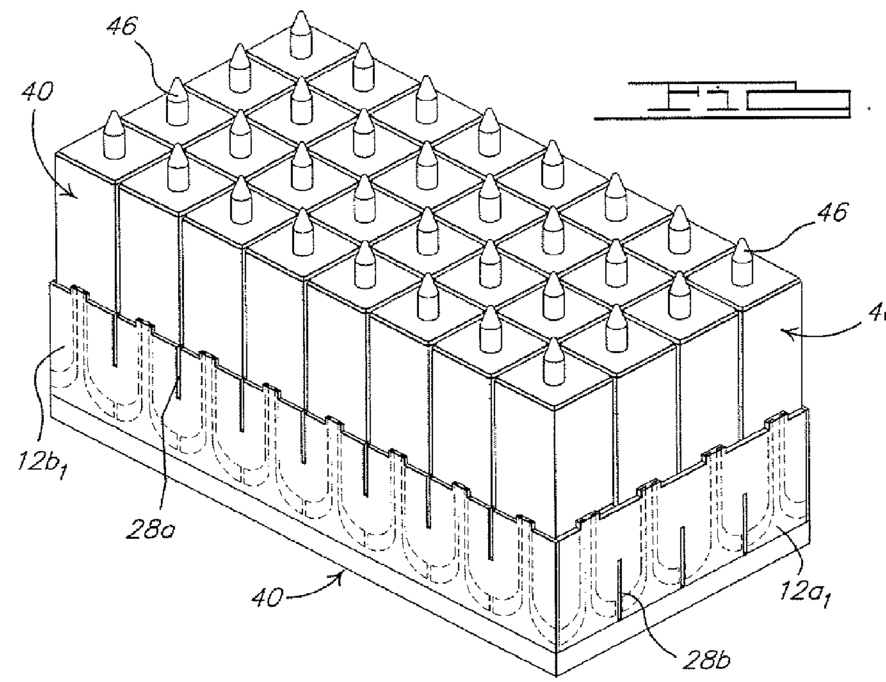
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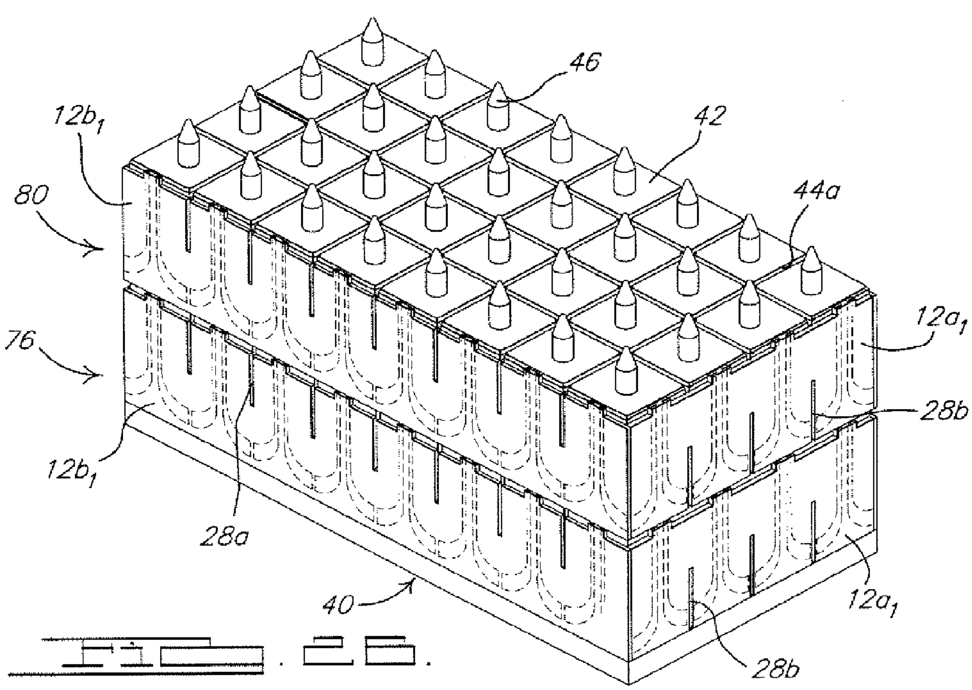
FIG. 25.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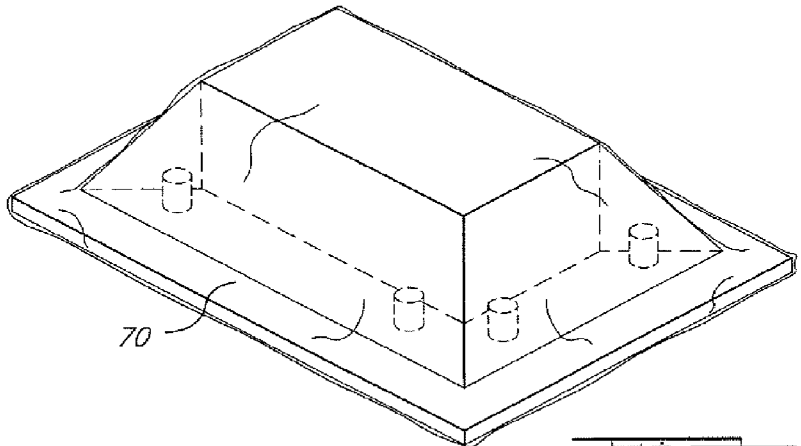
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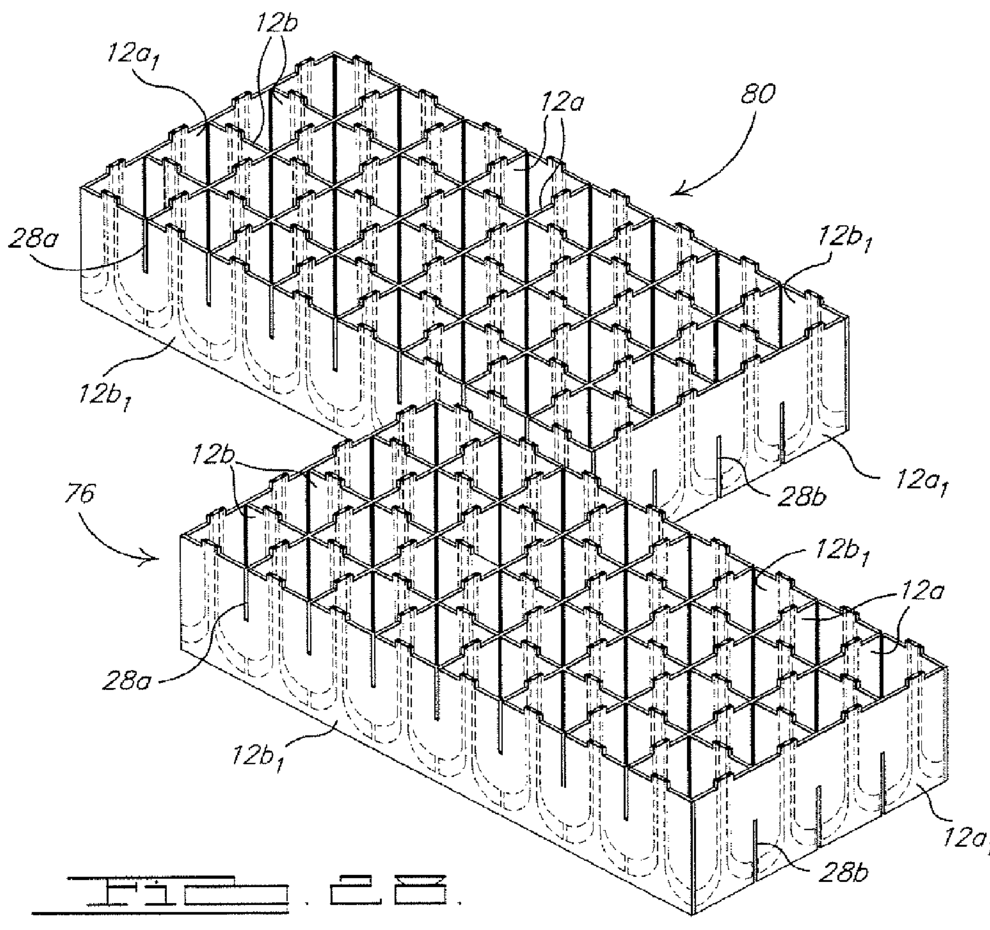
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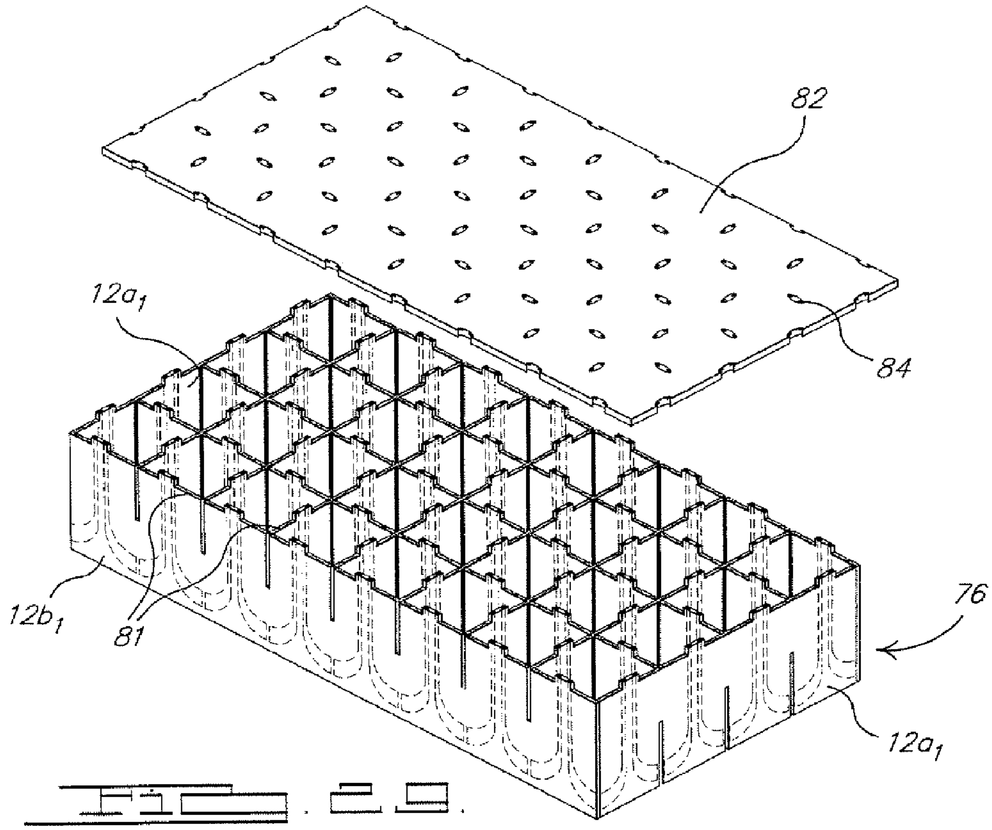
FIG. 28.



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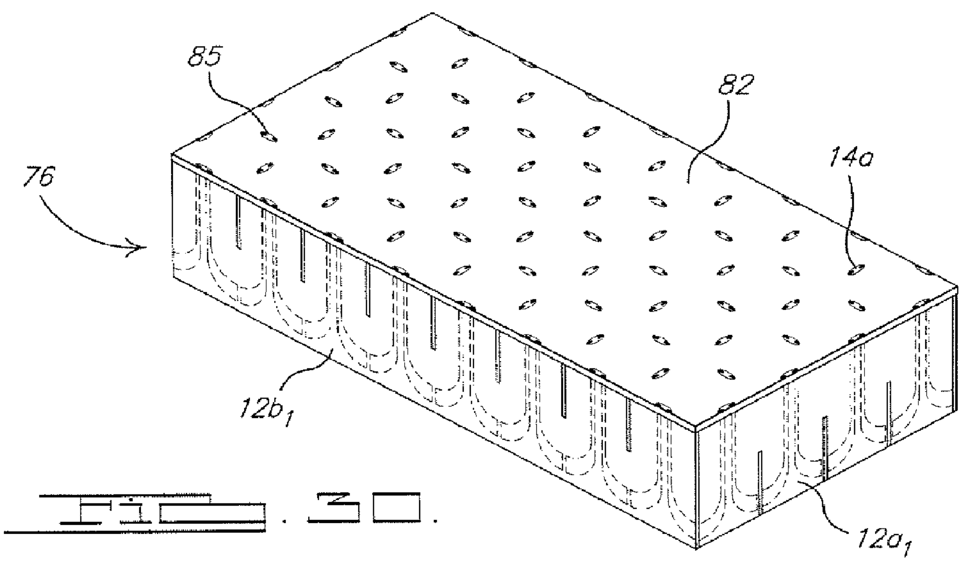

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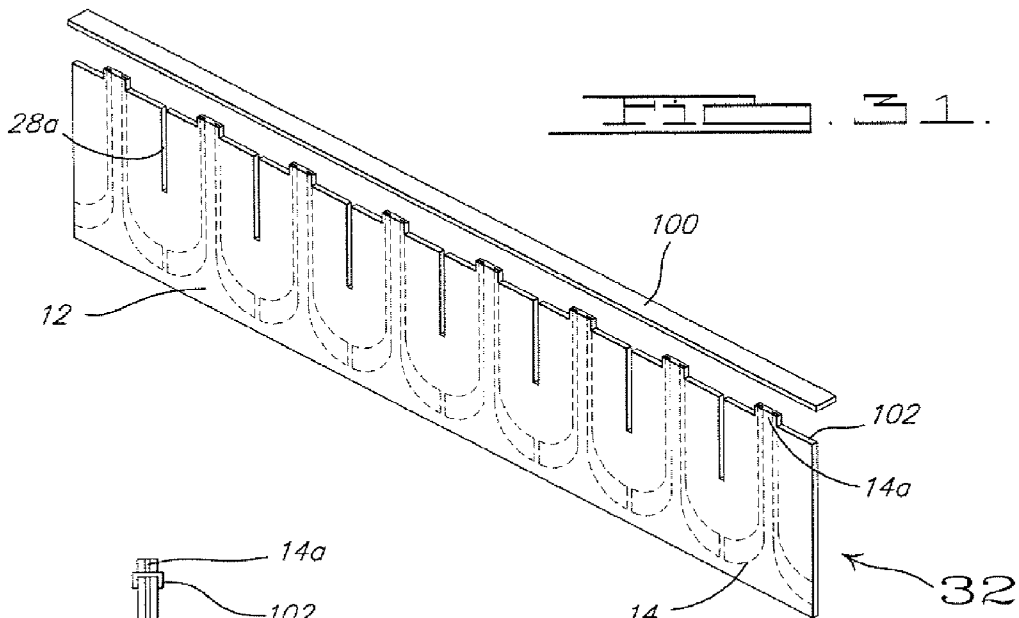

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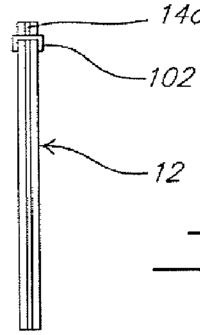

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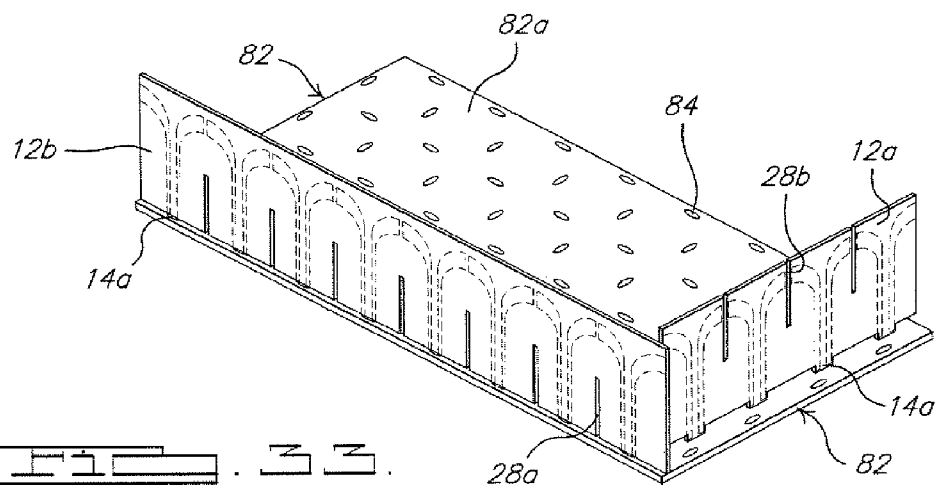

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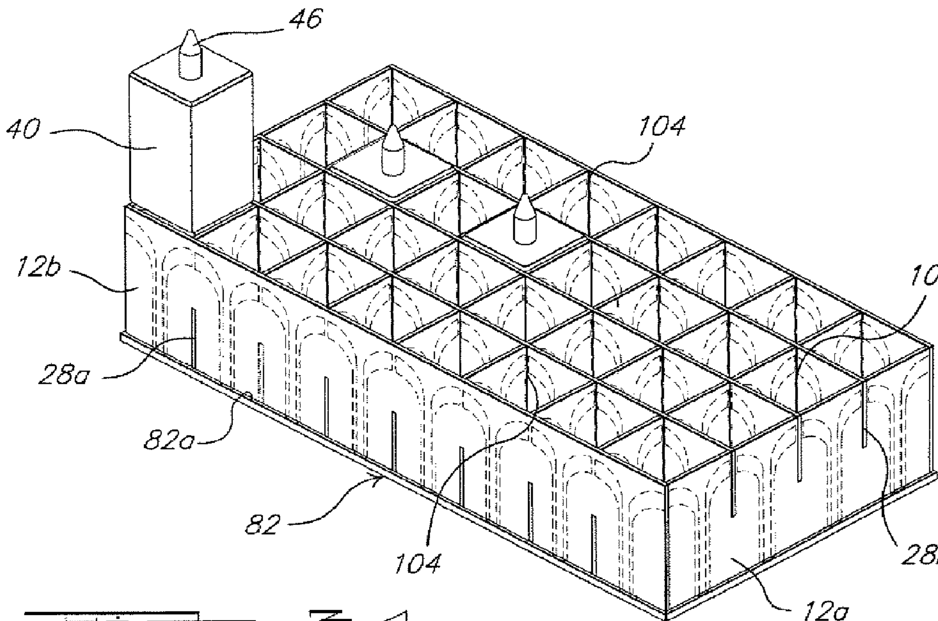

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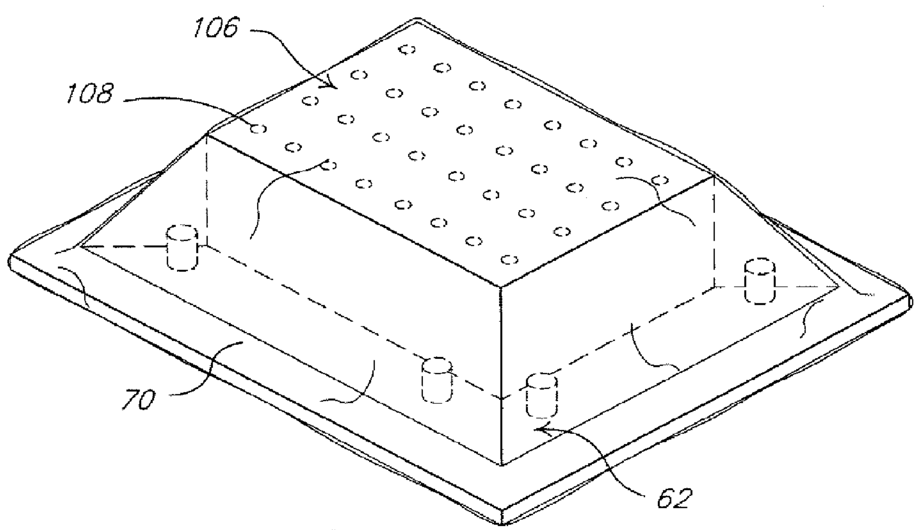
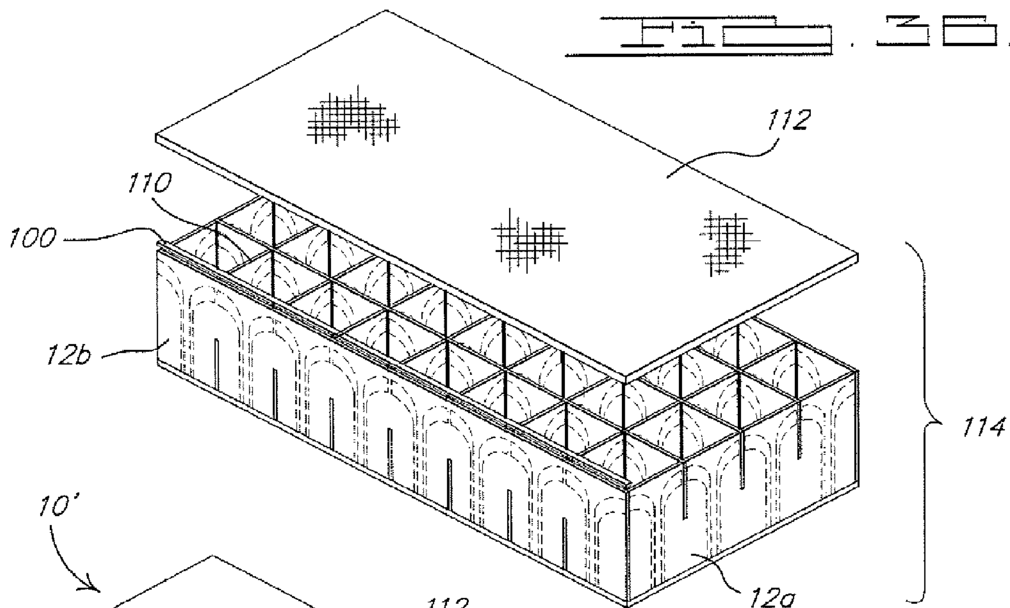
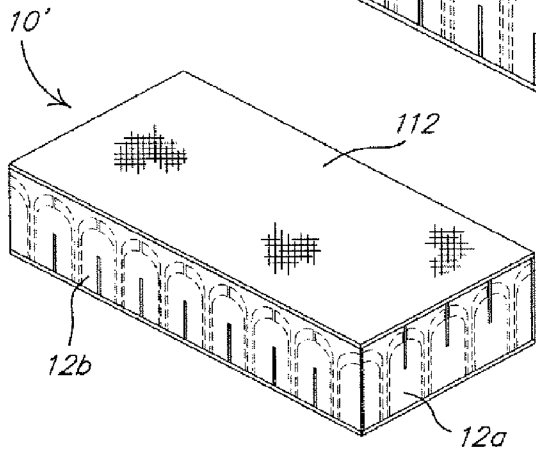


FIG. 35.

FIG. 36.





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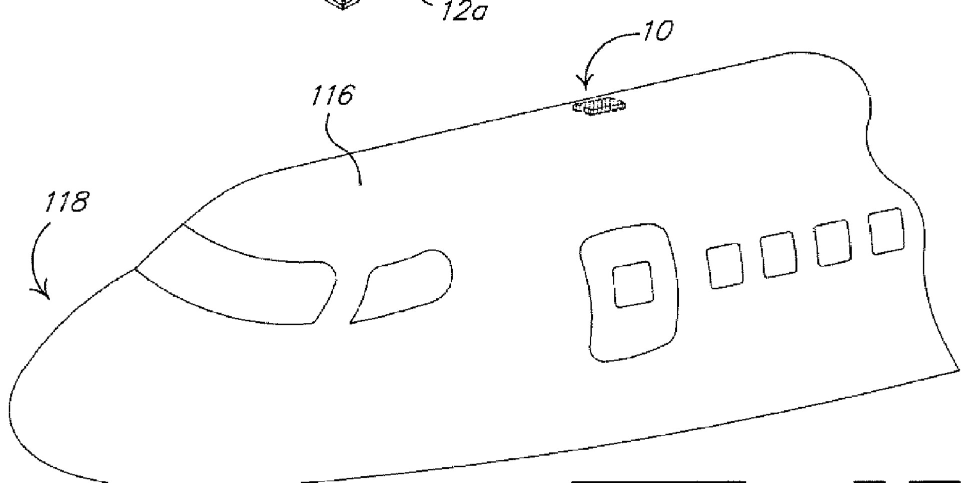


FIG. 38.

	Shear	Flatwise	Bending	Compression
For Antenna 10 Honeycomb Like Core Of 11.7 Lbs./Sq. Ft.	557 lb	698 lb	1015 lb	3100 lb
Conventional 12 Lbs./Sq. Ft. HRP® Core	531 lb	625 lb	1000 lb	2080 lb

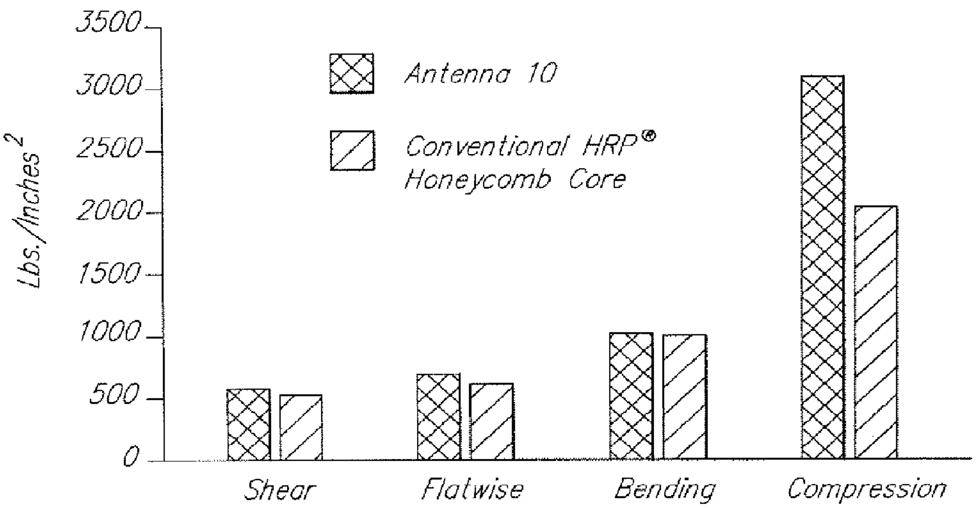
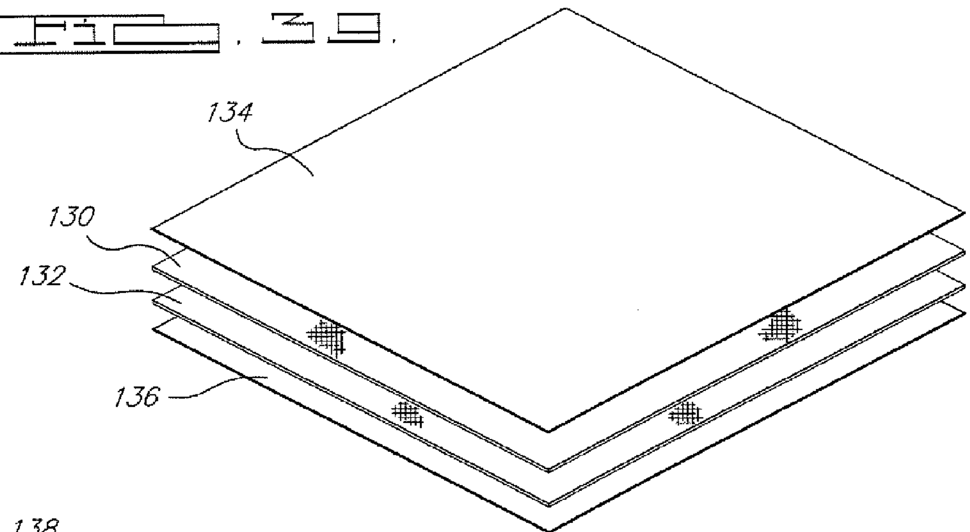
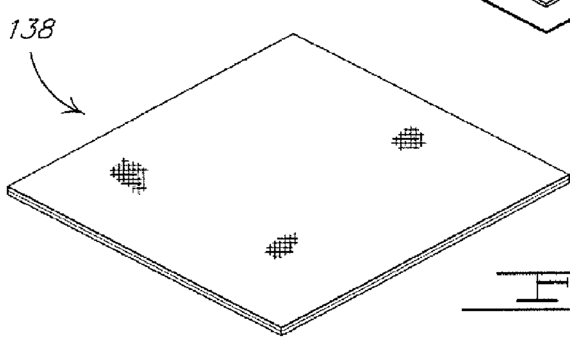


FIG. 38a.

FIG. 39.





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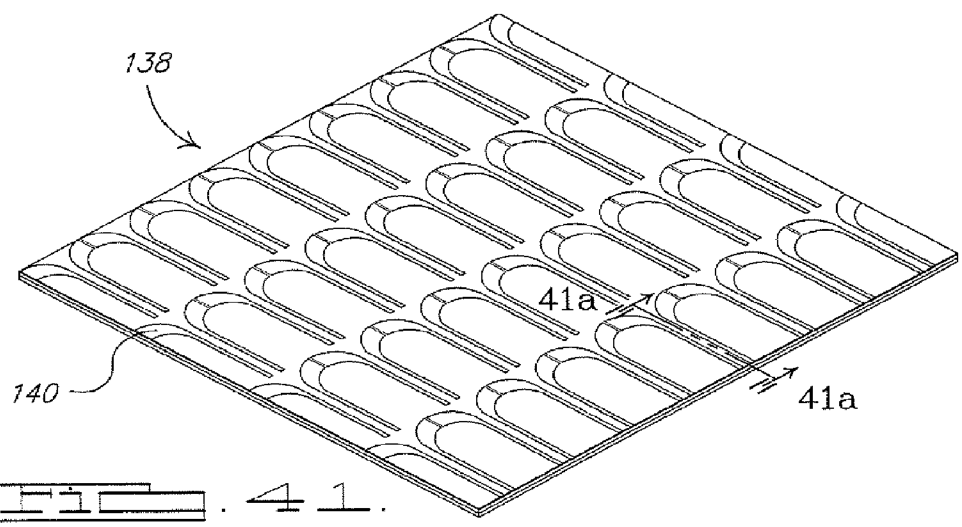

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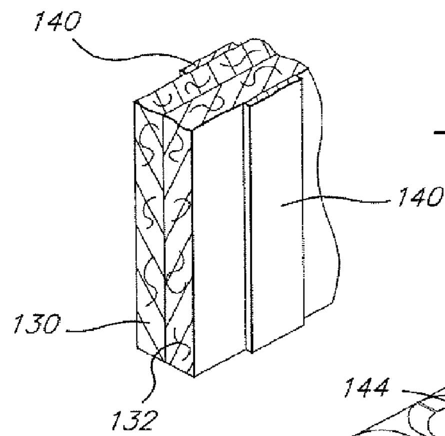


FIG. 41a.

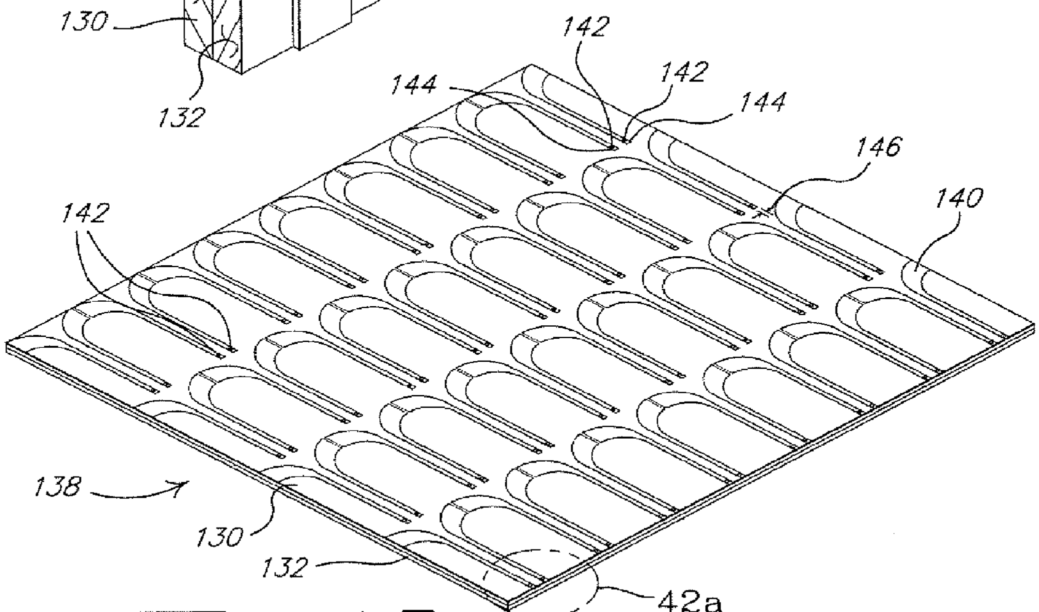
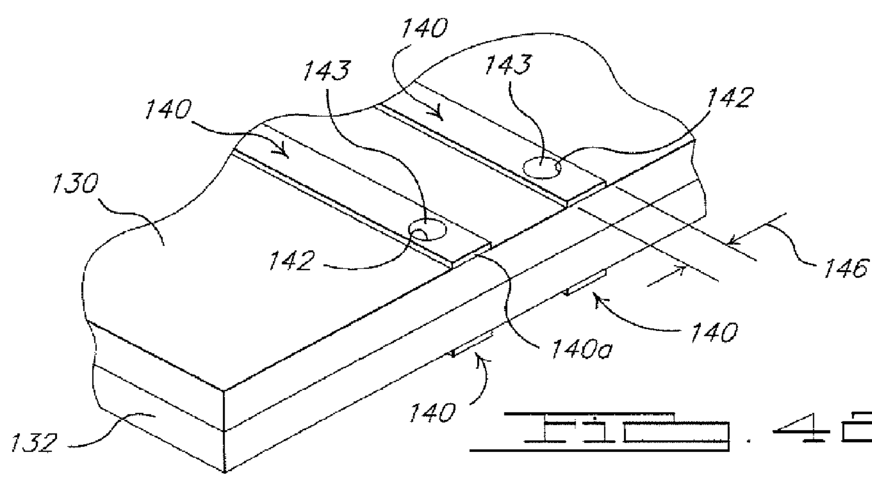


FIG. 42.



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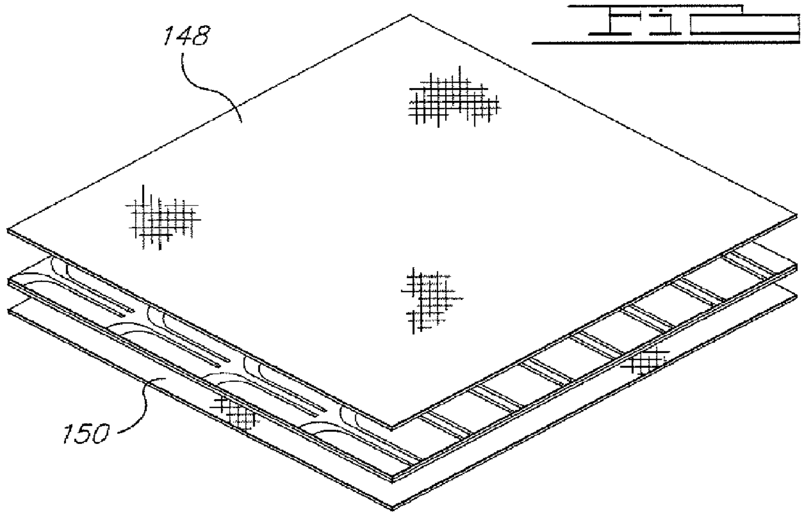

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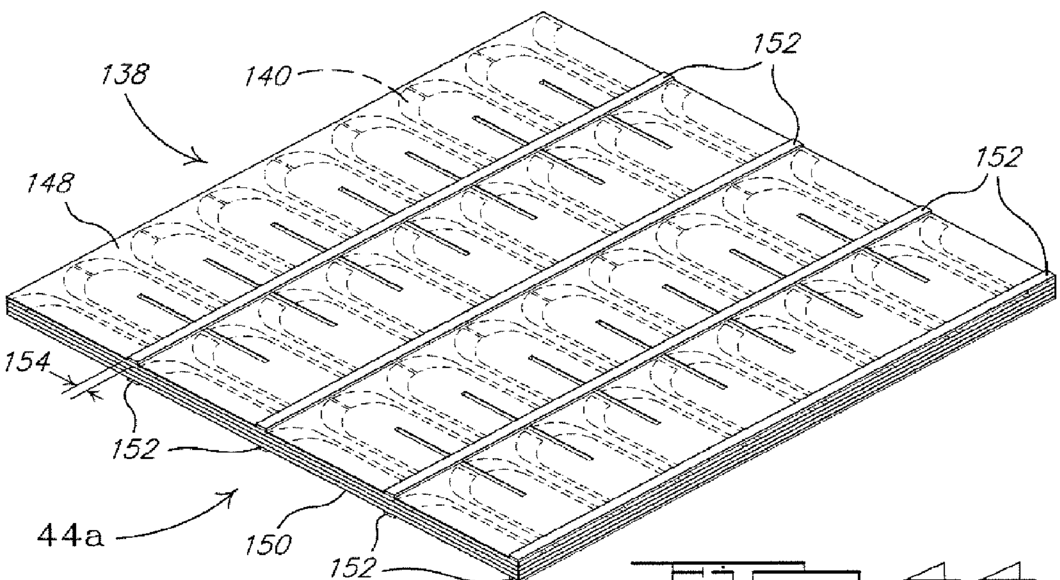

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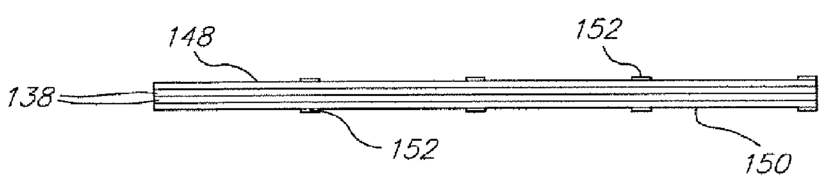
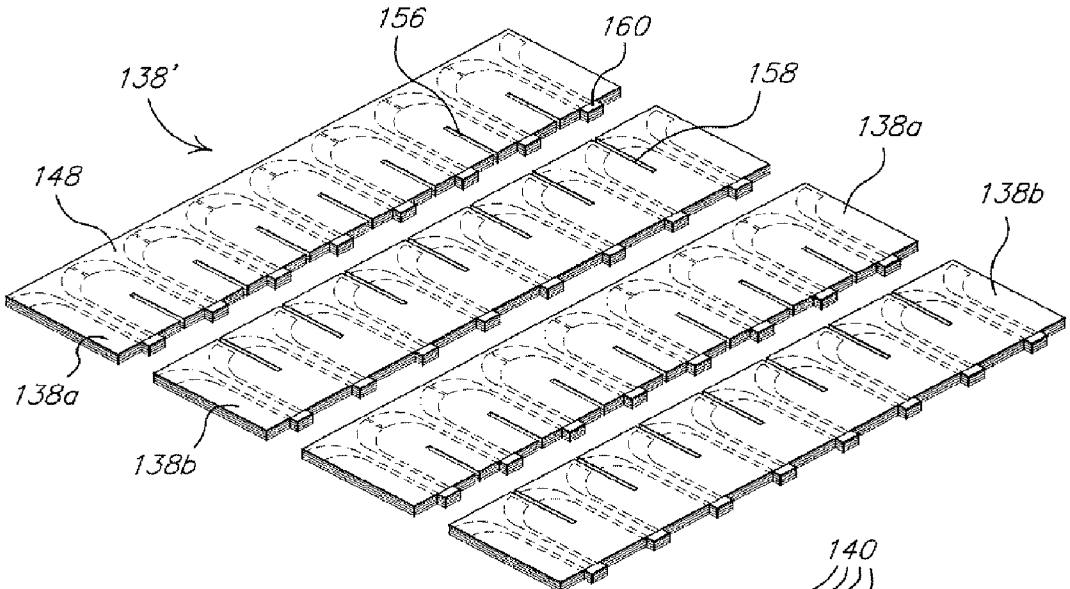


FIG. 44a.



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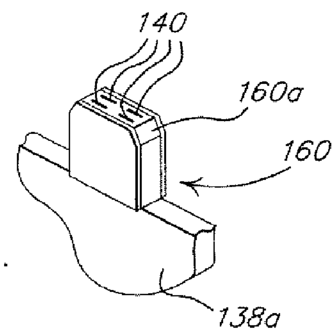

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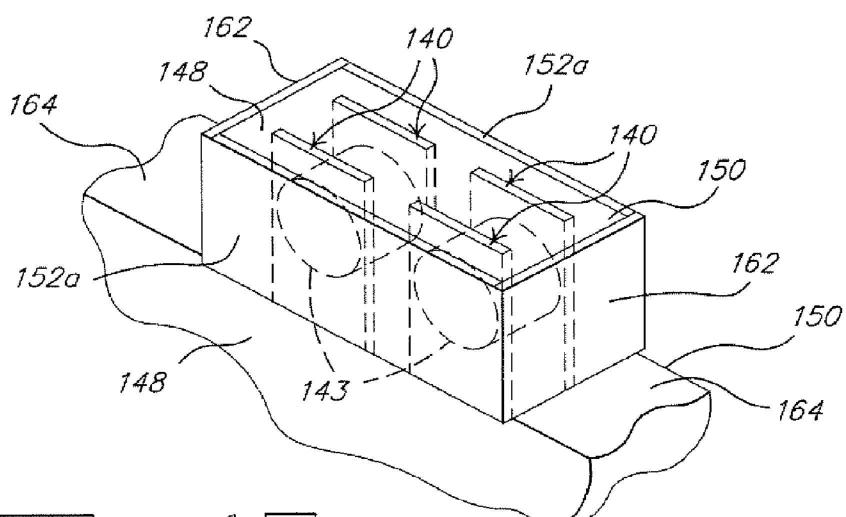

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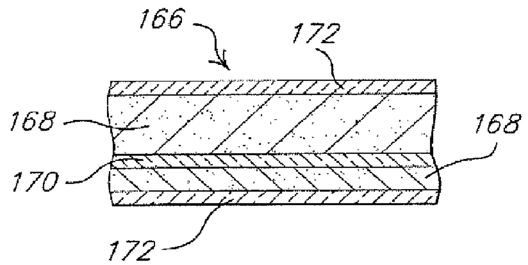

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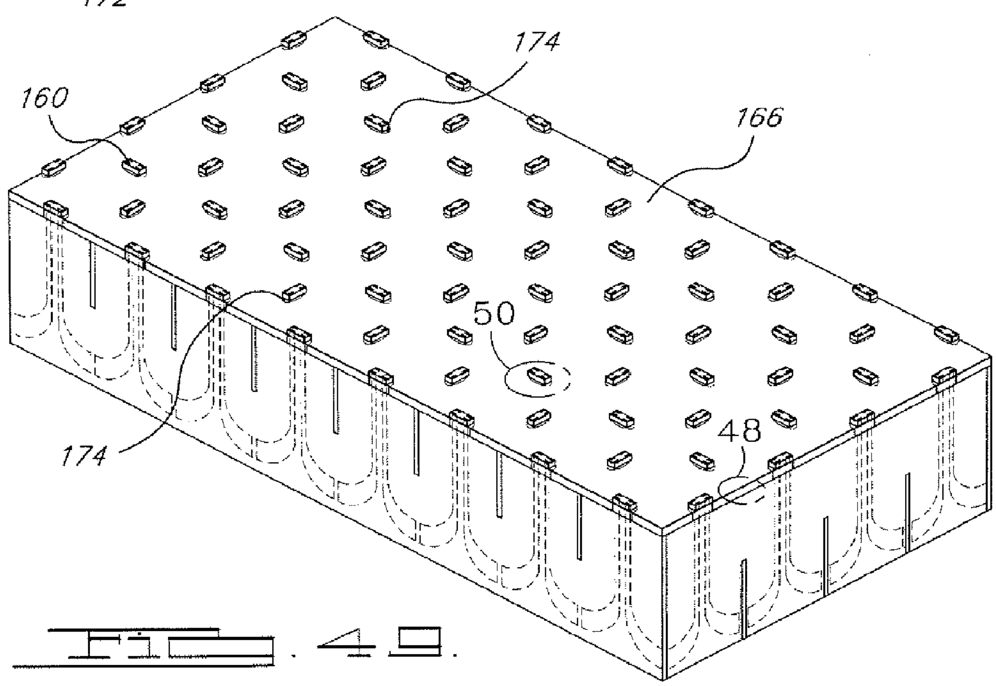

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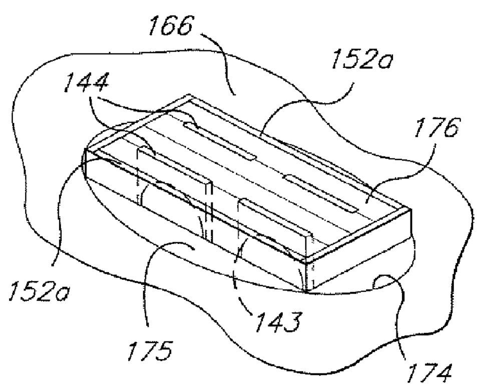


FIG. 50.

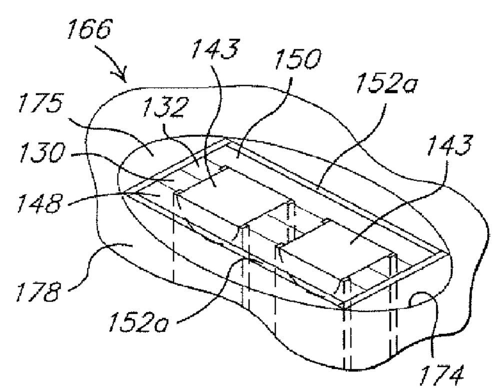
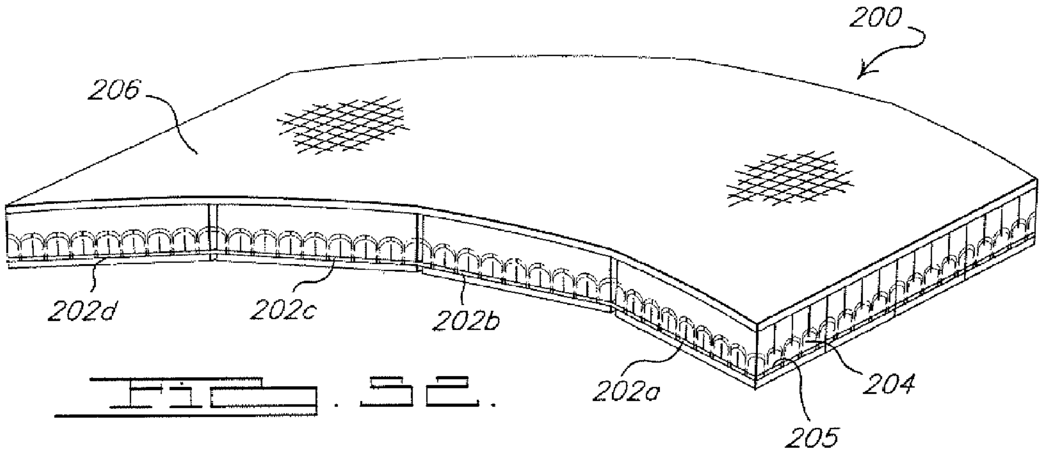


FIG. 51.



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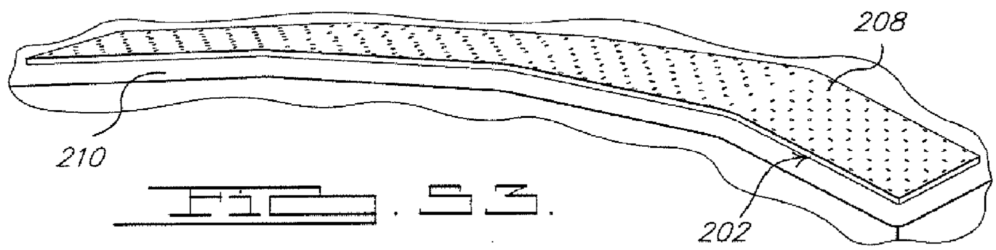

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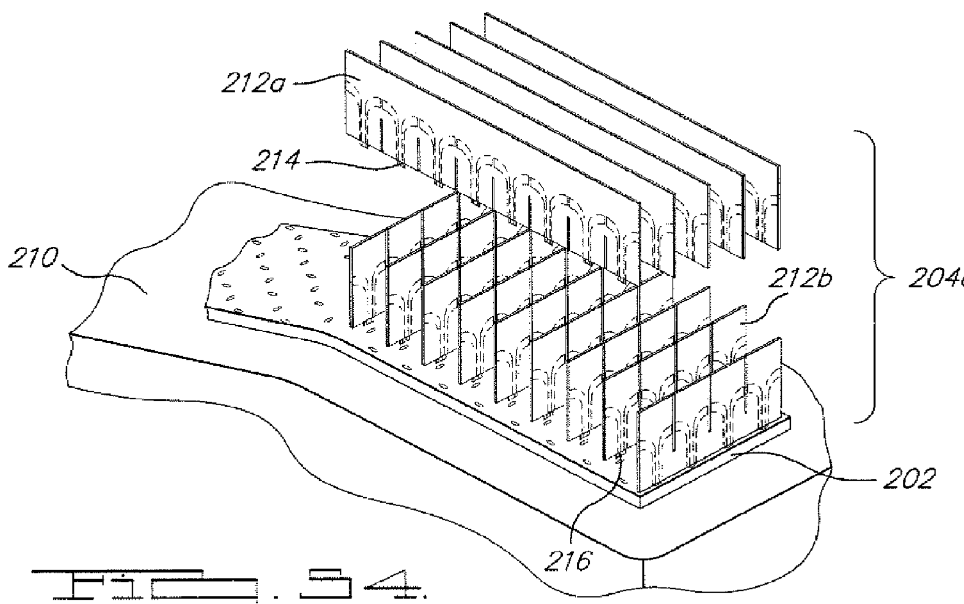


FIG. 54.

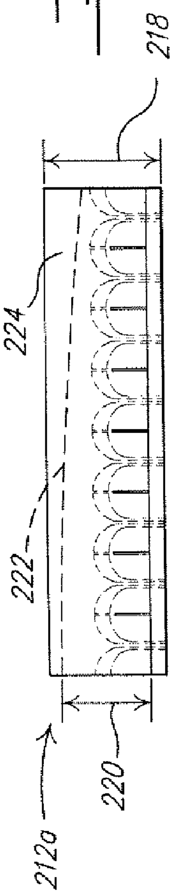


FIG. 55.

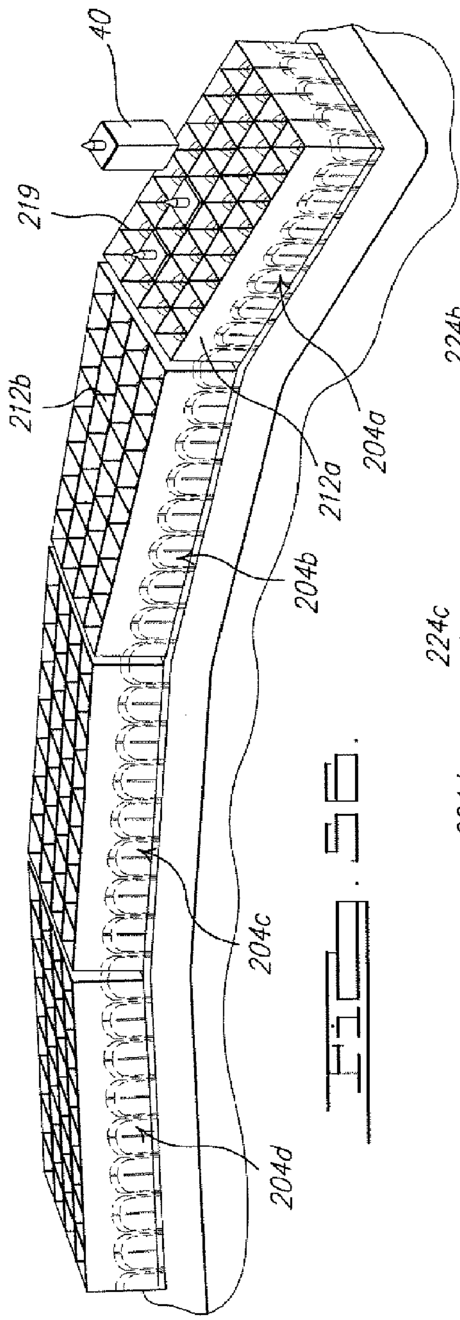


FIG. 56.

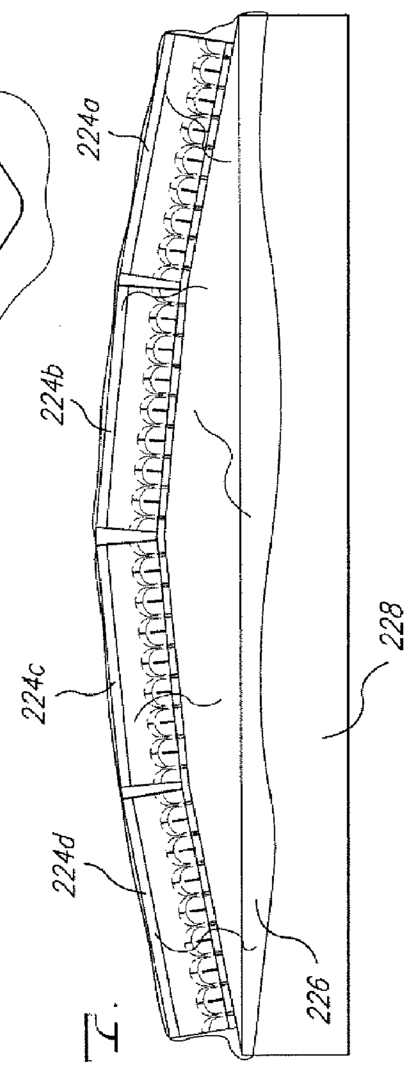


FIG. 57.

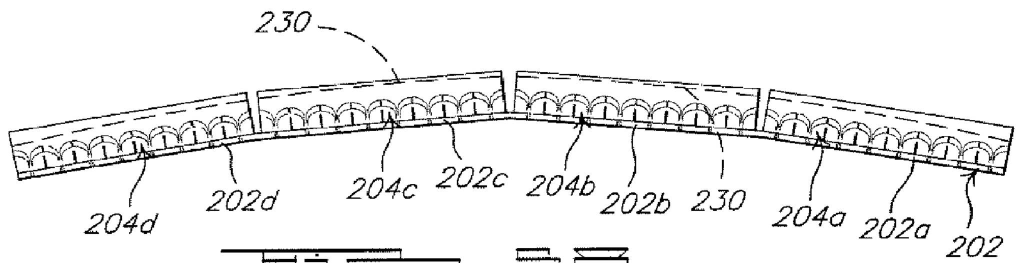


FIG. 58.

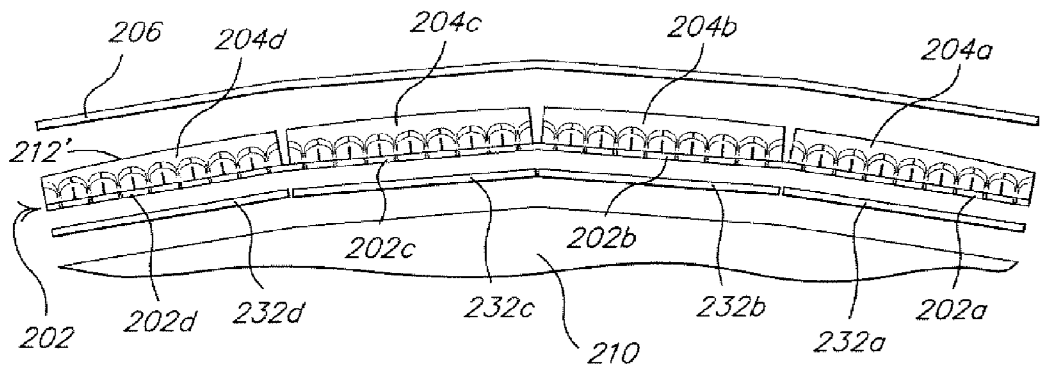


FIG. 59.

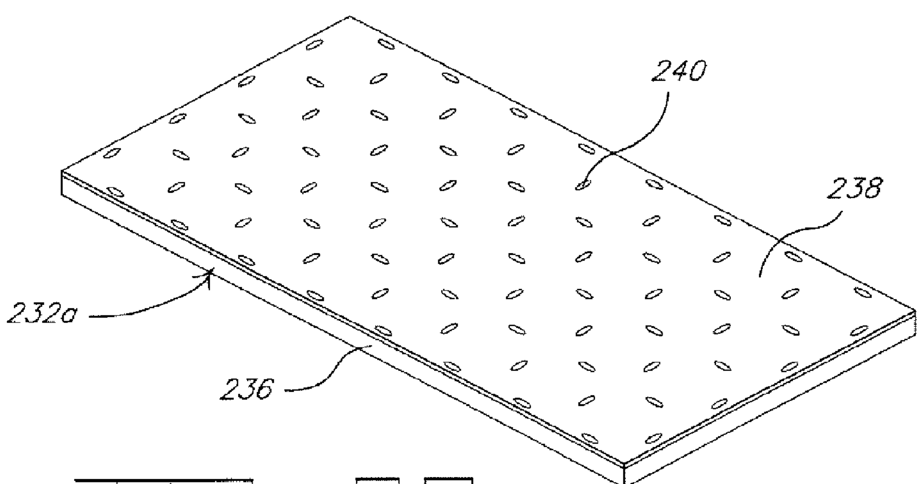
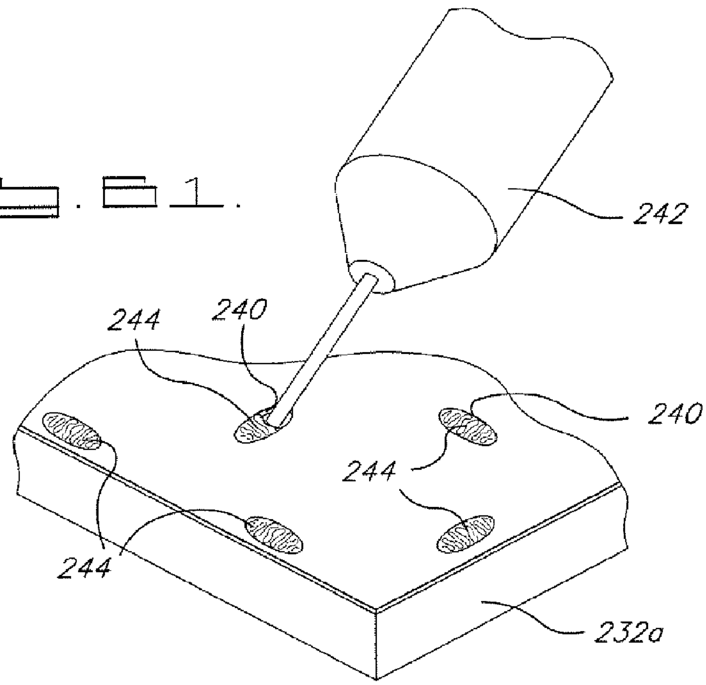


FIG. 60.

FIG. 61.


242
244
240
240
244
244
232a

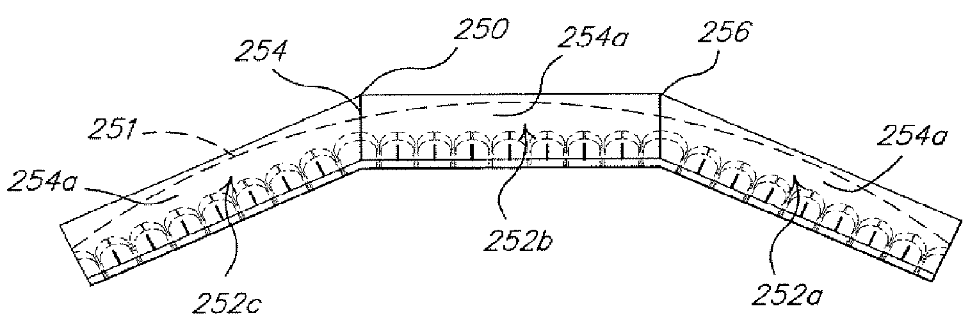

254
250
254a
256
251
254a
254a
252b
252c
252a

FIG. 62.

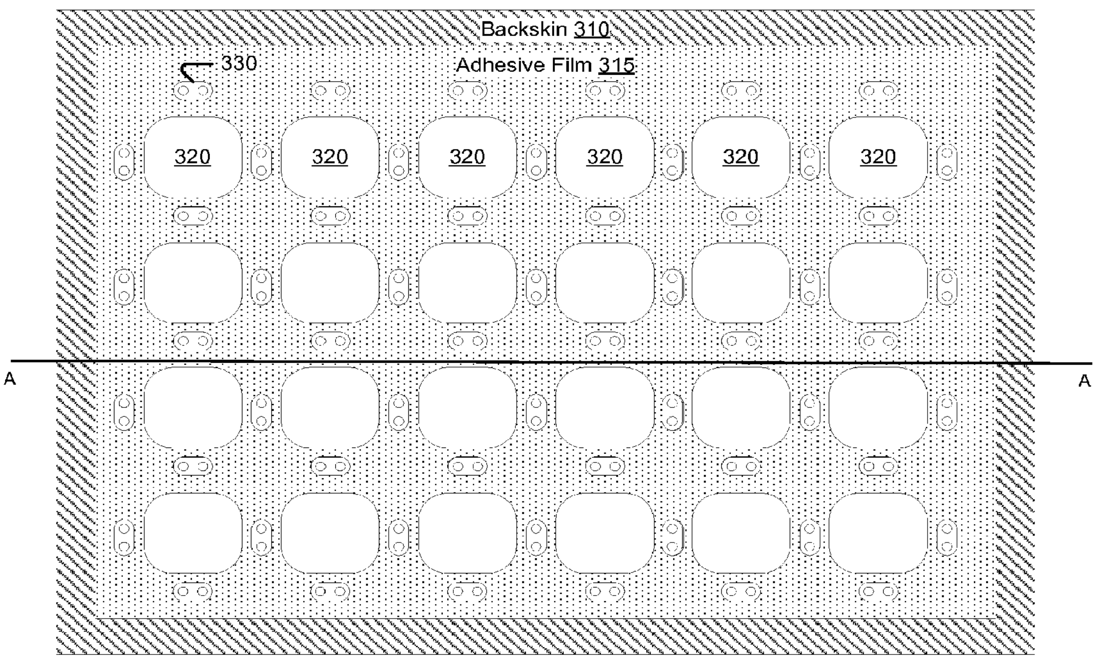


FIG. 63

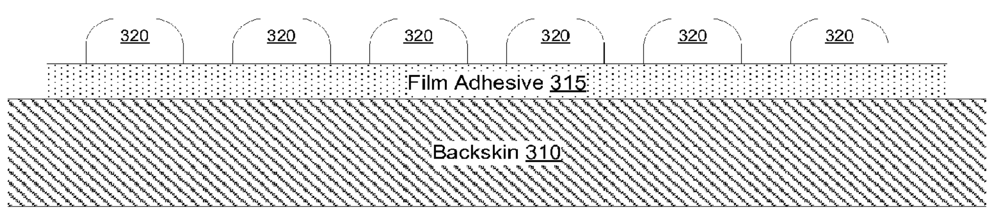


FIG. 64

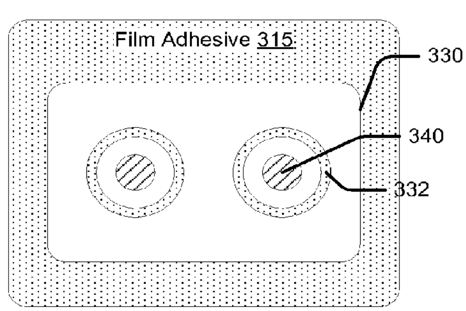


FIG. 65

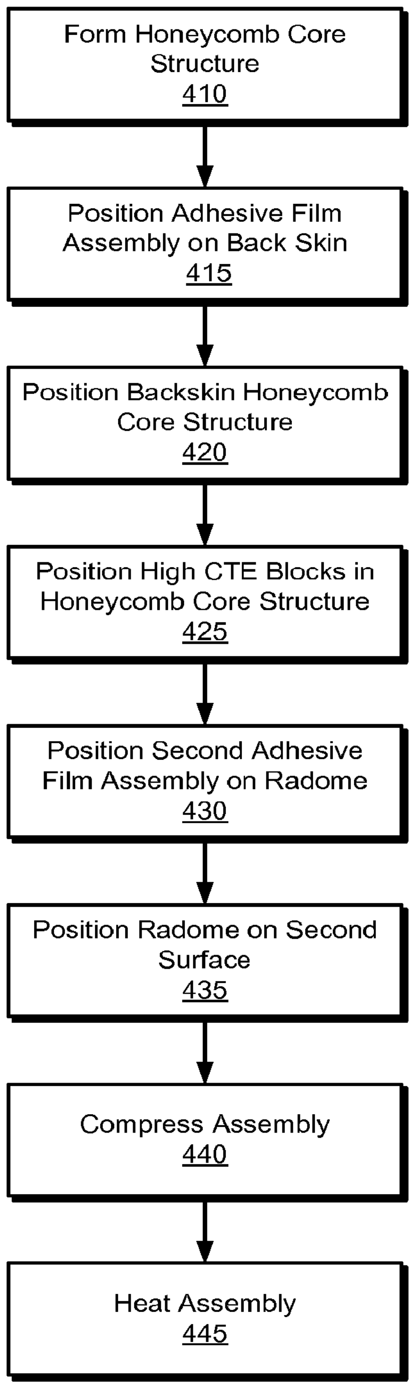

Form Honeycomb Core Structure 410
Position Adhesive Film Assembly on Back Skin 415
Position Backskin Honeycomb Core Structure 420
Position High CTE Blocks in Honeycomb Core Structure 425
Position Second Adhesive Film Assembly on Radome 430
Position Radome on Second Surface 435
Compress Assembly 440
Heat Assembly 445

FIG. 66

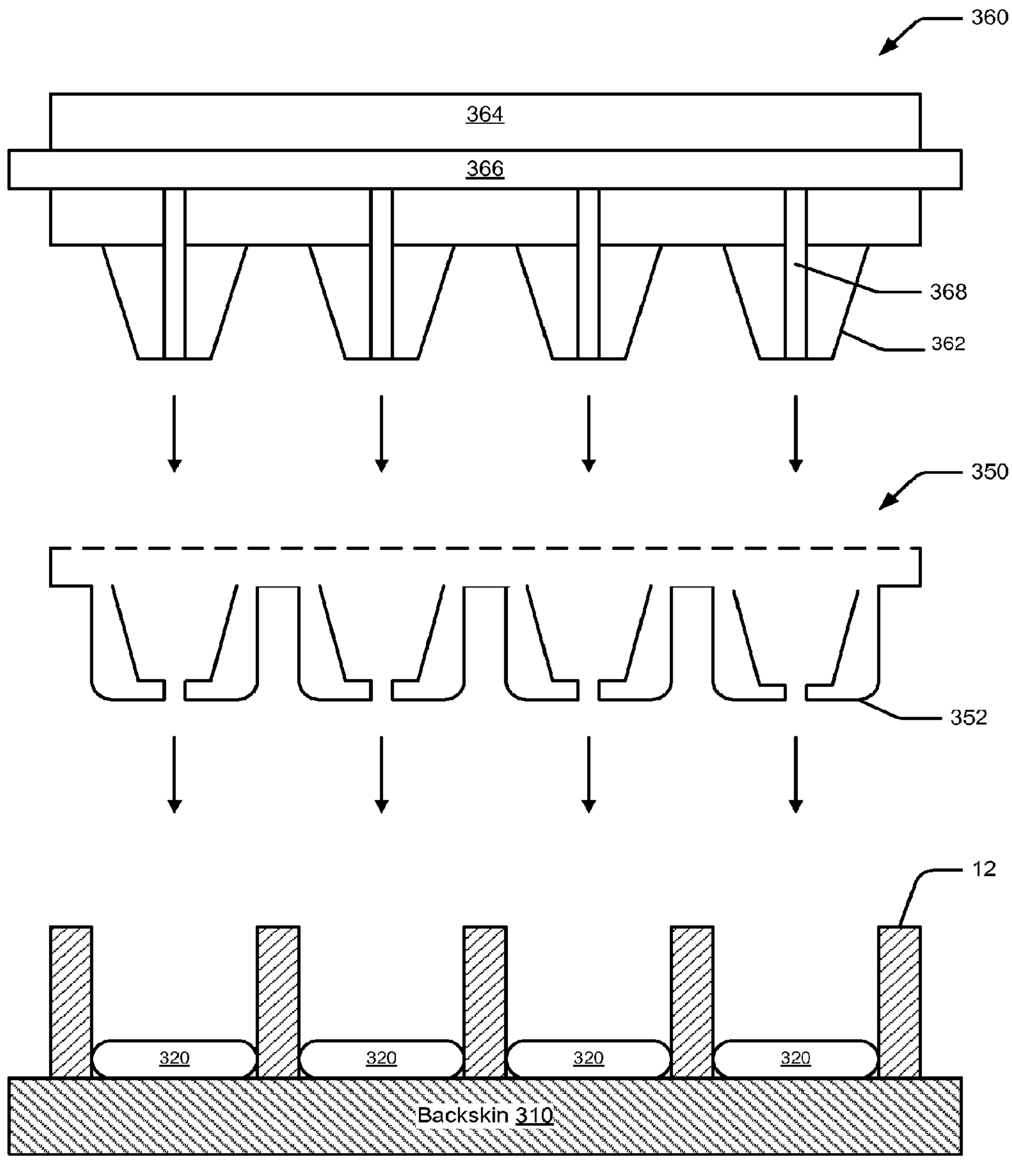


FIG. 67

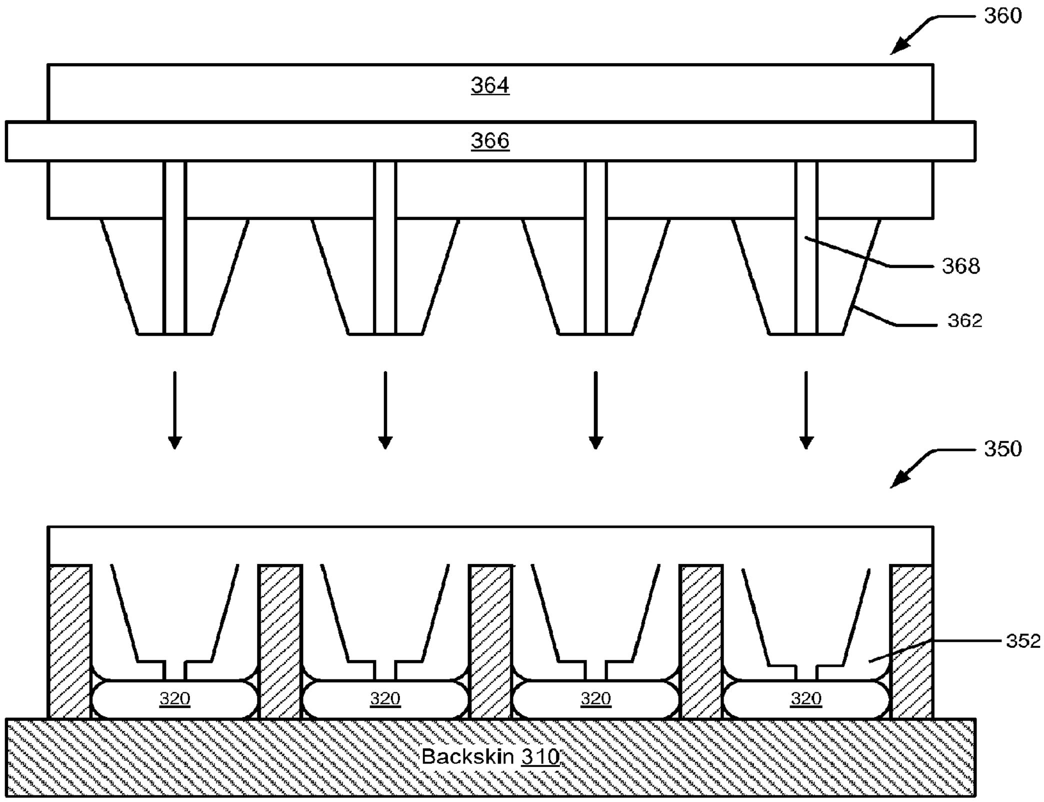

360
364
366
368
362
350
352
320
320
320
320
Backskin 310

FIG. 68

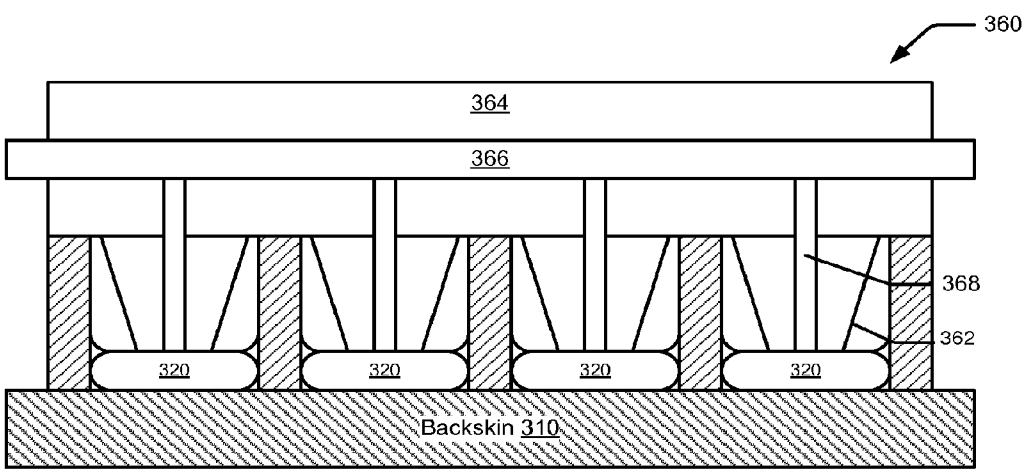

360
364
366
368
362
320
320
320
320
Backskin 310

FIG. 69

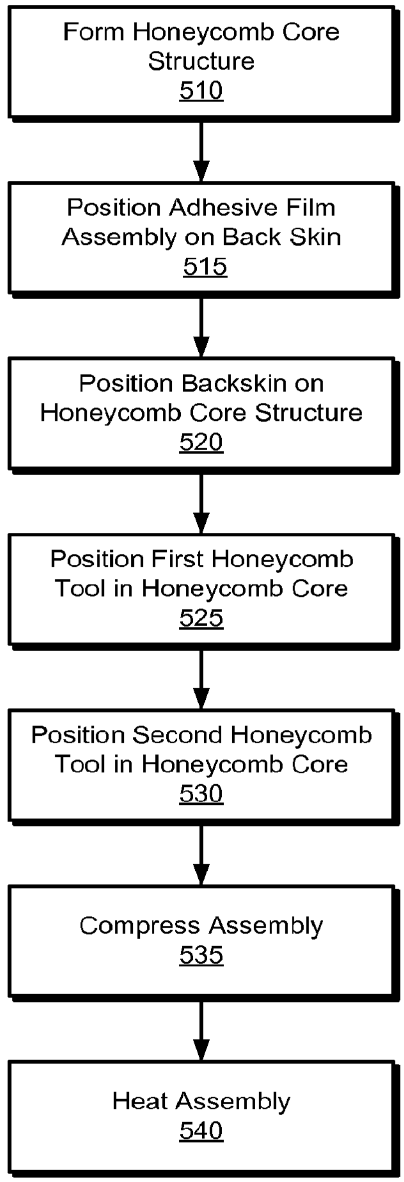

Form Honeycomb Core Structure 510
Position Adhesive Film Assembly on Back Skin 515
Position Backskin on Honeycomb Core Structure 520
Position First Honeycomb Tool in Honeycomb Core 525
Position Second Honeycomb Tool in Honeycomb Core 530
Compress Assembly 535
Heat Assembly 540

FIG. 70

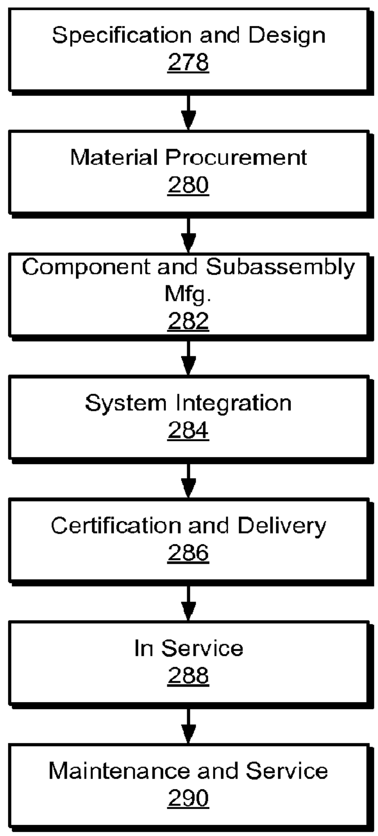

Specification and Design 278
Material Procurement 280
Component and Subassembly Mfg. 282
System Integration 284
Certification and Delivery 286
In Service 288
Maintenance and Service 290

Fig. 71

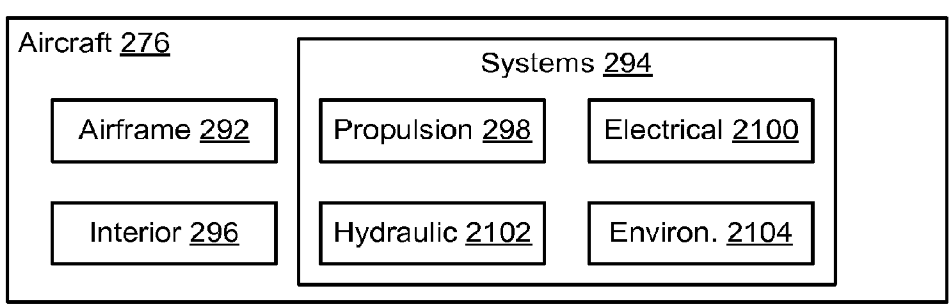

Aircraft 276
Systems 294
Airframe 292
Propulsion 298
Electrical 2100
Interior 296
Hydraulic 2102
Environ. 2104

Fig. 72

ANTENNA FABRICATION

This application is a divisional application of U.S. patent application Ser. No. 12/693,672, filed Jan. 26, 2010, now U.S. Pat. No. 8,446,330, issued on May 21, 2013.

BACKGROUND

The subject matter described herein relates to antenna systems. More particularly, the disclosure relates to antenna systems which can be used as a structural, load-bearing portion of a mobile platform and constructed to match an outer mold line of the area of the mobile platform into which the antenna system is integrated.

Present day mobile platforms, such as aircraft (manned and unmanned), spacecraft and even land vehicles, often require the use of an antenna aperture for transmitting and receiving electromagnetic wave signals. The antenna aperture is often provided in the form of a phased array antenna aperture having a plurality of antenna elements arranged in an X-Y grid-like arrangement on the mobile platform. The various components on which the radiating elements of the antenna are mounted add weight to the mobile platform. Often these components comprise aluminum blocks or other like substructures that add "parasitic" weight to the overall antenna aperture, but otherwise perform no function other than as a support structure for a portion of the antenna aperture. By the term "parasitic" it is meant weight that is associated with components of the antenna that are not directly necessary for transmitting or receiving operations.

An antenna array that is able to form a load bearing structure for a portion of a mobile platform would provide important advantages. For example, the number and nature of sensor functions capable of being implemented on the mobile platform could be increased significantly over conventional electronic antenna and sensor systems that require physical space within the mobile platform. Integrating the antenna into the structure of the mobile platform also eliminates less than desired effects on aerodynamics that may result when an antenna aperture is mounted on an exterior surface of a mobile platform. This could also eliminate the parasitic weight that would otherwise be present if the antenna aperture was formed as a distinct, independent component that required mounting on an interior or exterior surface of the mobile platform.

Thus, structural, load-bearing antenna arrays and methods to make the same may be desirable in aerospace applications and other communication applications.

SUMMARY

The subject matter described herein is directed to an antenna aperture having a construction making it suitable to be integrated as a structural, load bearing portion of the greater structure. In one embodiment the antenna aperture is constructed to form a load bearing portion of a mobile platform, and more particularly a portion of a wing, fuselage or door of an airborne mobile platform.

In some embodiments the antenna aperture forms a grid of antenna elements that can be manufactured, and scaled, to suit a variety of antenna and/or sensor applications. In one embodiment the antenna aperture comprises a honeycomb-like structure having a grid-like arrangement of dipole radiating elements. The antenna aperture does not require any metallic, parasitic supporting structures that would ordinarily be employed as support substrates for the radiating elements, and thus avoids the parasitic weight that such components typically add to an antenna

In various aspects, methods to form a load bearing antenna aperture and resulting apertures are disclosed. Thus, in one aspect there is provided a method to form a load bearing antenna aperture. In one embodiment the method comprises forming a honeycomb core structure having a plurality of wall sections, the wall sections including electromagnetic radiating elements. The lower surfaces of the wall sections define a first surface and upper surfaces of the wall sections define a second surface. The method further comprises securing a back skin to the first surface of the honeycomb core structure with an adhesive layer which comprises a layer of adhesive film and a paste adhesive disposed on the layer of adhesive film.

In another aspect there is provided a method to form a load bearing antenna aperture. In one embodiment the method comprises forming a honeycomb core structure having a plurality of wall sections. The wall sections include electromagnetic radiating elements, wherein lower surfaces of the wall sections define a first surface and upper surfaces of the wall sections define a second surface. The method further comprises depositing an adhesive layer on at least one of the first surface or the second surface, securing a back skin to the first surface of the honeycomb core structure, positioning a first honeycomb tool into the honeycomb core structure, positioning a second honeycomb tool into the first honeycomb tool to form an antenna aperture assembly, and curing the antenna aperture assembly

In yet another aspect there is provided a load bearing antenna aperture assembly. In one embodiment, the antenna aperture assembly comprises a honeycomb core structure having a plurality of wall sections, the wall sections including electromagnetic radiating elements, wherein lower surfaces of the wall sections define a first surface and upper surfaces of the wall sections define a second surface. The antenna aperture assembly further comprises a first adhesive pack disposed on the first surface, wherein the adhesive pack comprises a first layer of adhesive film, a second layer opposite the first layer of adhesive film, and a paste adhesive disposed between the first layer and the second layer. The assembly further comprises a back skin disposed on to the first surface of the honeycomb core structure by the first adhesive pack, and an antenna electronics board disposed adjacent at least a portion of the back skin. The electronics board comprises a plurality of antenna feed elements arranged in a predetermined pattern. The first layer of adhesive film comprises a plurality of rebates formed in a predetermined pattern corresponding to the predetermined pattern of antenna feed elements.

The features, functions and advantages discussed herein can be achieved independently in various embodiments described herein or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is described with reference to the accompanying figures.

FIG. **1** is an illustration of a perspective view of an antenna aperture in accordance with embodiments;

FIG. **2** is an illustration of a perspective view of a material sheet having a plurality of electromagnetic radiating elements;

FIG. **3** is an illustration of a perspective view of a pair of fabric prepreg plies positioned on opposite sides of the material sheet of FIG. **2**, ready to be bonded together to sandwich the material sheet;

FIG. **4** is an illustration of a perspective view of the subassembly of FIG. **3** after bonding;

FIG. **5** is an illustration of a perspective view of the assembly of FIG. **4** showing the slots that are cut to enable subsequent, interlocking assembly of wall portions of the antenna aperture;

FIG. **6** is an illustration of a view of the assembly of FIG. **5** with the assembly cut into a plurality of sections to be used as wall sections for the antenna aperture;

FIG. **7** illustrates the notches that are cut along one edge of each wall section to form teeth at a terminal end of each radiating element;

FIG. **8** is an illustration of a view of a tool used to align the wall sections of the aperture during an assembly process;

FIG. **9** is an illustration of a perspective view of one metallic block shown in FIG. **8**;

FIG. **10** is an illustration of a plan view of the lower surface of a top plate that is removably secured to each of the mounting blocks of FIG. **8** during the assembly process;

FIG. **11** is an illustration of a perspective view illustrating a plurality of wall sections being inserted in X-direction slots formed by the tool;

FIG. **12** is an illustration which shows the wall sections of FIG. **11** fully inserted into the tool, along with a pair of outer perimeter wall sections being temporarily secured to perimeter portions of the tool;

FIG. **13** is an illustration which illustrates a second plurality of wall sections being inserted into the X-direction rows of the tool;

FIG. **14** is an illustration which illustrates the second plurality of wall sections fully inserted into the tool;

FIG. **15** is an illustration which illustrates areas where adhesive is applied to edge portions of the wall sections;

FIG. **16** is an illustration which illustrates additional wall sections secured to the long, perimeter sides of the tool, together with a top plate ready to be secured over the locating pins of the metallic blocks;

FIG. **17** is an illustration of a view of the lower surface of the top plate showing the recesses therein for receiving the locating pins of each metallic block;

FIG. **18** is an illustration of a perspective view of the subassembly of FIG. **16** placed within a compaction tool **62** for compacting;

FIG. **19** is an illustration of a top view of the assembly of FIG. **18**;

FIG. **20** is an illustration of a perspective view of one of the sections of the tool shown in FIG. **18**;

FIG. **21** is an illustration of a view of the tool of FIG. **18** in a compaction bag, while a compaction operation is being performed;

FIG. **22** is an illustration which illustrates the two independent subassemblies formed during a compaction step of FIG. **21** after removal from the compacting tool;

FIG. **23** is an illustration which illustrates Y-direction wall portions being inserted into one of the previously formed subassemblies shown in FIG. **22**;

FIG. **24** is an illustration which shows the areas in which adhesive is placed for bonding intersecting areas of the wall sections;

FIG. **25** is an illustration which shows the subassembly of FIG. **24** after it has been lowered onto the alignment tool;

FIG. **26** is an illustration which shows both of the aperture subassemblies positioned on the alignment tool and ready for compacting and curing;

FIG. **27** is an illustration which illustrates the subassembly of FIG. **26** again placed within the compaction tool initially shown in FIG. **18**;

FIG. **28** is an illustration which shows the two independent aperture subassemblies formed after removal from the tool in FIG. **27**;

FIG. **29** is an illustration which illustrates a back skin being secured to one of the antenna aperture assemblies of FIG. **28**;

FIG. **30** is an illustration which illustrates the filled holes in the back skin, thus leaving only teeth on the radiating elements exposed;

FIG. **31** is an illustration of a perspective view of the wall section and an adhesive strip for use in connection with an alternative preferred method of construction of the antenna aperture;

FIG. **32** is an illustration of an end view of the wall section of FIG. **31** with the adhesive strip of FIG. **31**;

FIG. **33** is an illustration of a perspective view of the wall sections being secured to a back skin;

FIG. **34** is an illustration of a view of the wall sections secured to the backskin with the metallic blocks being inserted into the cells formed by the wall sections;

FIG. **35** is an illustration of a view of the assembly of FIG. **34** being vacuum compacted;

FIG. **36** is an illustration of a view of a radome positioned over the just-compacted subassembly, with adhesive strips being positioned over exposed edge portions of the wall sections;

FIG. **37** is an illustration of a view of the compacted and cured assembly of FIG. **36**;

FIG. **38** is an illustration which illustrates the antenna aperture integrally formed with a fuselage of an aircraft;

FIG. **38*a*** is an illustration of a graph illustrating the structural strength of the antenna aperture relative to a conventional phenolic core structure;

FIG. **39** is an illustration which shows an alternative preferred construction for the wall sections that employs prepreg fabric layers sandwiched between metallic foil layers;

FIG. **40** is an illustration which illustrates the layers of material shown in FIG. **39** formed as a rigid sheet;

FIG. **41** is an illustration which illustrates one surface of the sheet shown in FIG. **40** having electromagnetic radiating elements;

FIG. **41*a*** is an illustration of an end view of a portion of the sheet of FIG. **41** illustrating the electromagnetic radiating elements on opposing surfaces of the sheet;

FIG. **42** is an illustration which illustrates the holes and electrically conductive pins formed at each feed portion of each electromagnetic radiating element;

FIG. **42*a*** is an illustration which shows in enlarged, perspective fashion the electrically conductive pins that are formed at each feed portion;

FIG. **43** is an illustration which illustrates the material of FIG. **42** being sandwiched between an additional pair of prepreg fabric plies;

FIG. **44** is an illustration which illustrates metallic strips being placed along the feed portions of each electromagnetic radiating element;

FIG. **44*a*** is an illustration which illustrates the metallic strips placed on opposing surfaces of the sheet shown in FIG. **44**;

FIG. **45** is an illustration which illustrates the sheet of FIG. **40** cut into a plurality of lengths of material that form wall sections with each wall section being notched such that the feed portions of adjacent radiating elements form a tooth;

FIG. **46** is an illustration which shows an enlarged perspective view of an alternative preferred form of one tooth in which edges of the tooth are tapered;

FIG. **47** is an illustration which illustrates an enlarged portion of one of the teeth of the wall section shown in FIG. **45**;

FIG. **48** is an illustration which shows a portion of an alternative preferred construction of a back skin for the antenna aperture;

FIG. **49** is an illustration which illustrates an antenna aperture constructed using the back skin of FIG. **48**;

FIG. **50** is an illustration of a highly enlarged perspective view of one tooth projecting through the back skin of FIG. **49**; and

FIG. **51** is an illustration of an enlarged perspective view of the tooth of FIG. **50** after the tooth has been ground down flush with a surface of the back skin.

FIG. **52** is an illustration which illustrates a conformal, phased array antenna system in accordance with an alternative embodiments;

FIG. **53** is an illustration which illustrates a back skin of the antenna system of FIG. **52**;

FIG. **54** is an illustration which illustrates the assembly of wall sections forming one particular antenna aperture section of the antenna system of FIG. **52**;

FIG. **55** is an illustration of a planar view of one wall section of the antenna system of FIG. **54** illustrating the area that will be removed in a subsequent manufacturing step to form a desired contour for the one wall section;

FIG. **56** is an illustration of a perspective view of each of the four antenna aperture sections assembled onto a common back skin with metallic blocks being inserted into each of the cells formed by the intersecting wall sections;

FIG. **57** is an illustration which illustrates the subassembly of FIG. **56** being vacuum compacted;

FIG. **58** is an illustration which illustrates the compacted and cured assembly of FIG. **56** with a dashed line indicating the contour that the antenna modules will be machined to meet;

FIG. **59** is an illustration of an exploded perspective illustration of the plurality of antenna electronics circuit boards and the radome that are secured to the antenna aperture sections to form the conformal antenna system;

FIG. **60** is an illustration of an enlarged perspective view of an antenna electronics printed circuit board illustrating a section of adhesive film applied thereto with portions of the film being removed to form holes;

FIG. **61** is an illustration of a highly enlarged portion of one corner of the circuit board of FIG. **60** illustrating electrically conductive epoxy being placed in each of the holes in the adhesive film; and

FIG. **62** is an illustration of an end view of an alternative preferred embodiment of the antenna system in which wall portions that are used to form each of the antenna aperture sections are shaped to minimize the areas of the gaps between adjacent edges of the modules;

FIG. **63** is an illustration of a top, planar illustration of a back skin and an adhesive assembly, according to embodiments;

FIG. **64** is an illustration of a cross-sectional planar illustration of a back skin and an adhesive assembly taken along a longitudinal axis A-A as illustrated in FIG. **63**, according to embodiments;

FIG. **65** is an illustration of a close-up illustration of a section a rebate in the adhesive assembly covering the back skin;

FIG. **66** is an illustration of a flowchart illustrating operations in a method to make an antenna aperture, according to embodiments;

FIGS. **67-69** are illustrations of a cross-sectional views of a tooling assembly and an antenna assembly, according to embodiments;

FIG. **70** is an illustration of a flowchart illustrating operations in a method to make an antenna aperture, according to embodiments.

FIG. **71** is a flow diagram of an aircraft production and service methodology, according to embodiments.

FIG. **72** is a block diagram of an aircraft, according to embodiments.

DETAILED DESCRIPTION

The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the scope of the claims, its application, or uses.

Referring to FIG. **1**, there is shown an antenna aperture **10** in accordance with an embodiment. The antenna aperture **10** essentially forms a load bearing honeycomb-like structure that can be readily integrated into composite structural portions of mobile platforms without an undesirable change in the overall strength of the structural portion. Further, the antenna aperture does not add significant additional weight beyond what would be present with a conventional honeycomb core, sandwich-like construction technique that does not incorporate an antenna capability.

The aperture **10** includes a plurality of wall sections **12** interconnected to form a honeycomb or grid-like core section. Each wall section **12** includes a plurality of electromagnetic radiating elements **14** embedded therein. While FIG. **1** illustrates an X-Y grid-like (i.e., honeycomb-like) arrangement presenting generally square shaped openings, other grid arrangements are possible. For example, a honeycomb or grid-like core structure having hexagonally shaped openings can also be formed. Accordingly, the substantially perpendicular layout of the wall sections **12** that form antenna aperture **10** is intended merely to show one preferred grid-like layout for the radiating elements **14**. The type of grid selected and the overall size of the antenna aperture **10** will depend on the needs of a particular application with which the aperture **10** is to be used.

The preferred antenna aperture **10** does not require the use of metallic substrates for supporting the radiating elements **14**. The antenna aperture **10** therefore may not have an undesirable parasitic weight penalty. The antenna aperture **10** is a lightweight structure making it especially well suited for aerospace applications.

The preferred aperture **10** provides sufficient structural strength to be capable of replacing a load bearing structure. For example, in mobile platform applications, the antenna aperture **10** can be used as a primary structural component in an aircraft, spacecraft or rotorcraft. Other possible applications may be with ships or land vehicles. Since the antenna aperture **10** can be integrated into the structure of the mobile platform, it may not negatively impact the aerodynamics of the mobile platform as much as would be the case with an antenna aperture that is required to be mounted on an external surface of an otherwise highly aerodynamic, high speed mobile platform.

With further reference to FIG. **1**, the antenna aperture **10** further includes a back skin **16**, a portion of which has been cut away to better reveal the grid-like arrangement of wall sections **12**. The back skin **16** has openings **18** which allow "teeth" **14***a* of each electromagnetic radiating component **14** to project to better enable electrical connection of the radiating elements **14** with other electronic components.

Construction of Wall Sections

Referring now to FIG. **2**, a substrate layer **20** is formed with a plurality of the radiating elements **14** on its surface with the elements **14** being formed, for example, in parallel rows on the substrate **20**. In one preferred form the substrate **20** comprises a sheet of Kapton® polyimide film having a thickness of preferably about 0.0005-0.003 inch (0.0127 mm-0.0762 mm) The Kapton® film substrate **20** is coated with a copper foil that is then etched away to form the radiating elements **14** so that the elements **14** have a desired dimension and relative spacing. Other structures or arrangements are possible.

In FIG. **3**, the substrate **20** is placed between two layers of resin rich impregnated fabric **22** and **24** and then cured flat in an oven or autoclave, typically for a period of 2-6 hours. The impregnated fabric **22** for example without limitation comprises Astroquartz® fibers preimpregnated with Cyanate Ester resin to provide the desired electrical properties, especially dielectric and loss tangent properties. Other composite materials may also be used, such as fiberglass with epoxy resin.

As shown in FIG. **4**, the component **26** forms a lightweight yet structurally rigid sheet with the radiating elements **14** sandwiched between the two impregnated fabric layers **22** and **24**. Referring to FIG. **5**, assembly slots **28** having portions **28***a* and **28***b* are then cut into the component **26** at spaced apart locations. Slots **28** facilitate intersecting assembly of the wall portions **12** (FIG. **1**). Slots **28** are for example and without limitation preferably water jet cut or machine routed into the component **26** to penetrate through the entire thickness of the component **26**. Making the component **26** in large flat sheets may allow a manufacturer to take advantage of precision, high rate manufacturing techniques involving copper deposition, silk screening, etc. Further, by including features in the flat component **26** such as the slots **28** and the radiating elements **14**, one can insure very precise placement and repeatability of the radiating elements, which in turn allows coupling to external electronics with a high degree of precision.

Referring to FIG. **6**, the component **26** is then cut into a plurality of sections that form wall portions **12**. If the antenna aperture **10** will be substantially rectangular in shape, rather than square, then an additional cut will be made to shorten the length of those wall portions **12** that will form the short side portions of the aperture **10**. For example, a cut may be made along dash line **30** so that the resultant length **32** may be used to form one of the two shorter sides of the aperture **10** of FIG. **1**. Distance **34** represents the overall height that the antenna aperture **10** will have. The wall sections **12** may also be planed to a specific desired thickness. In one preferred implementation, a thickness of between about 0.015 inch-0.04 inch (0.381 mm-1.016 mm) for the wall sections **12** is preferred.

Referring to FIG. **7**, an edge of each wall section may be cut to form notches **36** between terminal ends of each radiating element **14**. The notches **36** enable the terminal ends of each radiating element **14** to form the teeth **14***a* (also illustrated in FIG. **1**). However, the formation of teeth **14***a* is optional.

Assembly of Wall Sections

Referring to FIG. **8**, a tool that is used to support the wall sections **12** during forming of the aperture **10** is shown. The tool **38** comprises a base **40** that is used to support a plurality of blocks **42** in an orientation to form a plurality of perpendicularly extending slots **28**. For convenience, one group of slots **28** has been designated as the "X-direction" slots **28** and one group as the "Y-direction" slots **28**.

Referring to FIG. **9**, one of the blocks **42** is shown in greater detail. Block **42** includes a main body **44** that is generally square in cross sectional shape. Upper and lower locating pins **46** and **48**, respectively, are located at an axial center of the main body **44**. Each block **42** is preferably formed from aluminum but may be formed from other metallic materials as well. The main body **44** of each metallic block **42** further preferably has radiused upper corners **44***a* and radiused longitudinal corners **44***b*. The metallic blocks **42** also preferably include a polished outer surface.

With brief reference to FIG. **10**, an upper surface **50** of the base plate **40** is shown. The upper surface **50** includes a plurality of precisely located recesses **52** for receiving each of the lower locating pins **48** of each metallic block **42**. The recesses **52** serve to hold the metallic blocks **42** in a spaced apart alignment that forms the X-direction slots **28** and the Y-direction slots **28**.

Referring to FIG. **11**, a first subplurality of the wall sections that will form the X-direction walls of the aperture **10** are inserted into the X-direction slots **28**. For convenience, these wall sections will be noted with reference numeral **12***a*. Each of the wall sections **12***a* include slots **28***b* and are inserted such that slots **28***b* will be adjacent the upper surface **50** of the base plate **40** once fully inserted into the X-direction slots **28**. Outermost wall sections $\mathbf{12}a_1$ may be temporarily held to longitudinal sides of the metallic blocks **42** by for example without limitation Mylar® PET film or Teflon® PTFE tape. FIG. **12** shows each of the wall sections **12***a* seated within the X-direction slots **28** and resting on the upper surface **50** of the base plate **40**.

Referring to FIG. **13**, a second vertical layer of wall sections **12***a* may then be inserted into the X-direction slots **28**. A second subplurality of wall sections $\mathbf{12}a_1$ are similarly secured along the short sides of the tool **38**. The second plurality of wall sections **12***a* rest on the first plurality. FIG. **14** shows the second subplurality of wall sections **12***a* fully inserted into the X-direction slots **28**.

Referring to FIG. **15**, beads of adhesive **54** are placed along edges of each of wall sections **12***a* and $\mathbf{12}a_1$. In FIG. **16**, Y-direction rows $\mathbf{12}b_1$ are then placed along the longer longitudinal sides of the tool **38** and are adhered to the edges of rows **12***a* and $\mathbf{12}a_1$ by the adhesive **54**. The entire assembly of FIG. **16** is then covered with a top plate **56**. Top plate **56** is also shown in FIG. **17** and has a lower surface **58** having a plurality of recesses **60** for accepting the upper locating pins **46** of each metallic block **42**. Top plate **56**, in combination with base plate **40**, thus holds each of the metallic blocks **42** in precise alignment to maintain the X-direction slots **28** and Y-direction slots **28** in a substantially perpendicular configuration.

Initial Bonding of Wall Sections

Referring to FIGS. **18** and **19**, the entire assembly of FIG. **16** is placed within four components **62***a*-**62***d* of a tool **62**. Each of sections **62***a*-**62***d* includes a pair of bores **64** that receive a metallic pin **66** therethrough. One of the tool sections **62***d* is shown in FIG. **20** and can be seen to be slightly triangular when viewed from an end thereof. In FIGS. **18** and **19** the pins **66** are received within openings in a table **68** to hold the subassembly of FIG. **16** securely during a cure phase. Tool **62**, as well as top plate **56** and base plate **40**, are all preferably formed from for example and without limitation Invar. In FIG. **21** the tool **62** is covered with a vacuum bag **70** and the subassembly within the tool **62** is bonded. Bonding typically takes from 4-6 hours. The blocks **42** expand during the compacting phase to help provide the compacting force applied to the wall sections **12**.

Referring to FIG. **22**, after the compacting step shown in FIG. **21** is performed, the tool **62** is removed, the top plate **56** is removed and a pair of independent subassemblies **72** and **74** each made up of wall sections **12***a*, **12***a*$_1$ and **12***b*$_1$ are provided. Each of subassemblies **72** and **74** form rigid, lightweight subassemblies.

Formation of Grid and Securing of Back Skin

Referring to FIG. **23**, the completion of subassembly **72** will be described. The completion of assembly of subassembly **74** is identical to what will be described for subassembly **72**. In FIG. **23**, a plurality of wall sections **12***b* are inserted into the Y-direction slots **28** of the subassembly **72** to form columns. The wall sections **12***b* are inserted such that slots **28***a* intersect with slots **28***b*. The resulting subassembly, designated by reference numeral **76**, is shown in FIG. **24**. Adhesive **78** is then placed at each of the interior joints of the subassembly **76** where wall portions **12***a* and **12***b* meet. The adhesive **78** may be applied with a heated syringe or any other suitable means that allows the corners where the wall sections **12** intersect to be lined with an adhesive bead.

Referring to FIG. **25**, the resulting subassembly **76** is placed over the tool **38** and then an subassembly **80**, formed from subassembly **74**, is placed on top of subassembly **76**. Any excess adhesive that rubs off onto the tapered edges **44***a* of each of the metallic blocks **42** is manually wiped off.

Referring to FIG. **27**, a second bond/compaction cycle is performed in a manner identical to that described in connection with FIGS. **18-21**. Again, the thermal expansion of the blocks **40** may help to provide the additional compaction force on the wall sections **12**.

Referring to FIG. **28**, after the bond/compaction operation of FIG. **27** is completed, the two subassemblies **80** and **76** are removed from the tool **62** and then from the tool **38**. Each of subassemblies **80** and **76** form rigid, lightweight, structurally strong assemblies having a plurality of cells **76***a* and **80***a*. The size of the cells **80***a*, **76***a* may vary depending on desired antenna performance factors and the load bearing requirements that the antenna aperture **10** must meet. The specific dimensions of the antenna elements **14** will generally be in accordance with the length and height of the individual cells **80***a*, **76***a*. In one preferred form suitable for antenna or sensor applications in the GHz range, the cells **76***a* and **80***a* are about 0.5 inch in length×0.5 inch in width×0.5 inch in height (12.7 mm×12.7 mm×12.7 mm). The overall length and width of each subassembly **76** and **80** will vary depending on the number of radiating elements **14** that are employed, but can be on the order of about 1.0 ft×1.0 ft (30.48 cm×30.48 cm), and subsequently secured adjacent to one another to form a single array of greater, desired dimensions. The fully assembled antenna system **10** may vary from several square feet in area to possibly hundreds of square feet in area or greater. While the cells **80***a*, **76***a* are illustrated as having a square shape, other shaped cells could be formed, such as triangular, round, hexagonal, etc.

Referring to FIG. **29**, beads of adhesive **81** are placed along each exposed edge of each of the wall sections **12**. A back skin **82** having a plurality of precisely machined openings **84** is then placed over each subassembly **80** and **76** such that the teeth **14***a* of each radiating element **14** project through the openings **84**. The back skin **82** is preferably an impregnated composite material sheet that has been previously cured to form a structurally rigid component. In one preferred form the back skin **82** is comprised of a plurality of layers of Astroquartz® impregnated fibers preimpregnated with Cyanate Ester resin. The thickness of the backskin **82** may vary as needed to suit specific load bearing requirements. The higher the load bearing capability required, the thicker the backskin **82** will need to be. In one preferred form the backskin **82** has a thickness of about 0.050 inch (1.27 mm), which together with wall sections **12** provides the aperture **10** with a density of about 8 lbs/cubic foot (361 kg/cubic meter). The backskin **82** could also be formed with a slight curvature or contour to match an outer mold line of a surface into which the antenna aperture **10** is being integrated.

In FIG. **30**, after the back skin **82** is placed on the assembly **76**, the openings **84** are filled with an epoxy **85** such that only the teeth **14***a* of each radiating element **14** are exposed. The back skin is then compacted onto the remainder of the subassembly and cured in an autoclave for preferably 2-4 hours at a temperature of about 250° F.-350° F., at a pressure of about 80-90 psi. The adhesive beads **81** and **54** form fillets that help to provide the aperture **10** with excellent structural strength.

Alternative Assembly Method of Wall Sections

Referring to FIGS. **31-37**, an alternative preferred method of constructing the antenna aperture **10** is shown. With this method, the wall sections **12** are assembled as a complete X-Y grid onto a backskin, then the entire assembly is cured in one step. Referring specifically to FIG. **31**, each wall section **12** has an adhesive strip **100** pressed over an edge **102** adjacent the teeth **14***a* of the radiating elements **14**. Adhesive strip **100** is preferably about 0.015 inch thick (0.38 mm) and has a width of preferably about 0.10 inch (2.54 mm). The strip **14** can be a standard, commercially available epoxy or Cyanate Ester film. The strip **100** is pressed over the teeth such that the teeth **14***a* pierce the strip **100**. The strip **100** is tacky and temporarily adheres to the upper edge **102**. Referring to FIG. **32**, portions of the adhesive strip **102** are folded over opposing sides of the wall section **12**. This is performed for each one of the X-direction walls **12***a* and each one of the Y-direction walls **12***b*. Referring to FIG. **33**, each of the wall sections **12***a* and **12***b* are then assembled onto the backskin **82** one by one. This involves carefully aligning and using sufficient manual force to press each of the teeth **14***a* on each wall section **12** through the openings **84** in the backskin **82**. The adhesive strips **102** help to hold each of the wall sections **12** in an upright orientation. The interlocking connections of the wall sections **12***a* and **12***b* also serve to temporarily hold the wall sections **12** in place.

Referring to FIG. **34**, adhesive beads **104** are then applied at each of the areas where wall sections **12***a* and **12***b* intersect. The metallic blocks **40** are then inserted into each of the cells formed by the wall sections **12***a* and **12***b*. The insertion of each metallic block **40** helps to form the adhesive beads **104** into fillets at the intersections of each of the wall sections **12**. Excess adhesive is then wiped off from the metallic blocks **40** and from around the intersecting areas of the wall sections **12**.

Referring to FIG. **35**, a metallic top plate **106** having a plurality of recesses **108** is then pressed onto the upper locating pins **46** of each of the metallic blocks **40**. The assembly is placed within vacuum bag **70** and bonded using tool **62**. Referring to FIG. **36**, the assembly is removed from the tool **62**, top plate **106** is removed, and the metallic blocks **40** are removed. Adhesive strips **100** and **110** are then pressed over exposed edge portions of each of the wall sections **12***a* and **12***b* in the same manner as described in connection with FIGS. **31** and **32**. Adhesive strips **110** are identical to strips **100** but just shorter in length. A precured front skin (i.e., radome) **112** is then positioned over the exposed edges of the wall sections **12***a* and **12***b* and pressed onto the wall sections **12***a* and **12***b* to form an assembly **114**. Assembly **114** is then vacuum compacted and cured in an autoclave for preferably 2-4 hours at a temperature of preferably about 250° F.-350° F. (121° C.-176° C.), and at a pressure of preferably around 85 psi. The cured assembly **114** is shown in FIG. **37** as antenna aperture **10'**. In FIG. **38**, the antenna aperture **10** is shown forming a portion of a fuselage **116** of an aircraft **118**.

The structural performance and strength of the antenna aperture **10** is comparable to a composite, HRP® core structure, as illustrated in FIG. **38***a*.

The antenna aperture **10**, **10'** is able to form a primary aircraft component for a structure such as a commercial aircraft or spacecraft. The antenna aperture **10**, **10'** can be integrated into a wing, a door, a fuselage or other structural portion of an aircraft, spacecraft or mobile platform. Other potential applications include the antenna aperture **10** forming a structural portion of a marine vessel or land based mobile platform.

Further Alternative Construction of Antenna Aperture

Referring to FIGS. **39-51**, an alternative method of constructing each of the wall sections **12** of the antenna aperture **10** will be described. Referring initially to FIG. **39**, two plies of resin rich impregnated fabric **130** and **132** are sandwiched between two layers of metallic material **134** and **136**. In one preferred form layers **130** and **132** are comprised of Astroquartz® fibers preimpregnated with Cyanate Ester resin. Metallic layers **134** and **136** preferably comprise copper foil having a density of about 0.5 ounce/ft.^{2} Layers **130-136** are cured flat in an autoclave to produce a rigid, unitary sheet **138** shown in FIG. **40**.

Referring to FIGS. **41** and **41***a*, portions of the metallic layers **134** and **136** are etched away to form dipole electromagnetic radiating elements **140** that are arranged in adjacent rows on both sides of the sheet **138**. Resistors or other electronic components could also be screen printed onto each of the radiating elements **140** at this point if desired.

Referring to FIGS. **42** and **42***a*, holes **142** are drilled completely through the sheet **138** at feed portions **144** of each radiating element **140**. The holes **142** are preferably about 0.030 inch (0.76 mm) in diameter but may vary as needed depending upon the width of the feed portion **144**. Preferably, the diameter of each hole **142** is approximately the same or just slightly smaller than the width **146** of each feed portion **144**. The holes **142** are further formed closely adjacent the terminal end of each of the feed portions **144** but inboard from an edge **140***a* of each feed portion **144**. Each hole **142** is filled with electrically conductive material **143** to form a "pin" or via that electrically couples an opposing, associated pair of radiating elements **140**.

Referring to FIG. **43**, sheet **138** is then sandwiched between at least a pair of additional plies of impregnated fabric **148** and **150**. Plies **148** and **150** are preferably formed from Astroquartz® fibers impregnated with Cyanate Ester resin. Each of the plies **148** and **150** may vary in thickness but are preferably about 0.005 inch (0.127 mm) in thickness.

Referring to FIGS. **44** and **44***a*, planar metallic strips **152** are placed along the feed portions **144** of each radiating element **140** on both sides of the sheet **138** to completely cover the holes **142**. Metallic strips **152**, in one preferred form, comprise copper strips having a thickness of preferably about 0.001 inch (0.0254 mm) and a width **154** of about 0.040 inch (1.02 mm) Again, these dimensions will vary in accordance with the precise shape of the radiating elements **140**, and particularly the feed portions **144** of each radiating element. Sheet **138** with the metallic strips **152** is then cured in an autoclave to form an assembly **138'**. Autoclave curing is performed at about 85 psi, 250° F.-350° F., for about 2-6 hours.

Referring to FIG. **45**, sheet **138'** is then cut into a plurality of lengths that form wall sections **138***a* and **138***b*. Wall sections **138***a* each then are cut to form notches **156**, such as by water jet cutting or any other suitable means. Wall sections **138***b* similarly have notches **158** formed therein such as by water jet cutting. The notches **156** and **158** could also be formed before cutting the sheet **138** into sections.

Each of the wall sections **138***a* and **138***b* further have material removed from between the feed portions **144** of the radiating elements **140** so that the feed portions form projecting "teeth" **160**. The teeth **160** are used to electrically couple circuit traces of an independent antenna electronics board to the radiating elements **140**.

Referring to FIG. **46**, each tooth **160** could alternatively be formed with tapered edges **160***a* to help ease assembly of the wall sections **138***a* and **138***b*.

Referring to FIG. **47**, one tooth **160** of wall section **138***a* is shown. Tooth **160** has resulting copper plating portions **152***a* remaining from the copper strips **152**. Side wall portions **162** of each tooth **160**, as well as surface portions **164** between adjacent teeth **160**, are also preferably plated with a metallic foil, such as copper foil, in a subsequent plating step. All four sidewalls of each tooth **160** are thus covered with a metallic layer that forms a continuous shielding around each tooth **160**.

Alternatively, each tooth **160** could be electrically isolated by using a conventional combination of electroless and electrolytic plating. This process would involve covering both sides of each of the wall sections **138***a* and **138***b* with copper foil, which is necessary for the electrolytic plating process. Each wall section **138***a* and **138***b* would be placed in a series of tanks for cleaning, plating, rinsing, etc. The electroless process leaves a very thin layer of copper in the desired areas, in this instance on each of the feed portions **144** of each radiating element **140**. The electrolytic process is used to build up the copper thickness in these areas. The process uses an electric current to attract the copper and the solution. After the electrolytic process is complete and the desired amount of copper has been placed at the feed portions **144**, each of the wall sections **138***a* and **138***b* are subjected to a second photo etching step which removes the bulk of the copper foil covering the surfaces of wall sections **138***a* and **138***b* so that only copper in the feed areas **144** is left.

Instead of Astroquartz® fibers, stronger structural fibers like graphite fibers, can be used. Thus, graphite fibers, which are significantly structurally stronger than Astroquartz® fibers, but which do not have the electrical isolation qualities of Astroquartz® fibers, can be employed in the back skin. For a given load-bearing capacity that the antenna aperture **10** must meet, a back skin employing graphite fibers will be thinner and lighter than a backskin of equivalent strength formed from Astroquartz® fibers. The use of graphite fibers to form the backskin therefore allows a lighter antenna aperture **10** to be constructed, when compared to a back skin employing Astroquartz® fibers, for a given load bearing requirement.

Referring to FIG. **48**, a cross section of a back skin **166** is shown that employs a plurality of plies of graphite fibers **168**. A metallic layer **170**, preferably formed from copper, is sandwiched between two sections of graphite plies **168**. Fiberglass plies **172** are placed on the two graphite plies **168**. The assembly is autoclave cured to form a rigid skin panel. Metallic layer **170** acts as a ground plane that is located at an intermediate point of thickness of the back skin **166** that depends on the precise shape of the radiating elements **140** employed, as well as other electrical considerations such as desired dielectric and loss tangent properties.

Referring to FIG. **49**, after the wall portions **138***a* and **138***b* are assembled onto the back skin **166** and autoclave cured as described in connection with FIG. **29**, each of the teeth **160** will project slightly outwardly through openings **174** in the back skin **166** as shown in FIG. **50**. Each tooth **160** will further be surrounded by epoxy **175** that fills each opening **174**.

The tooth **160** is subsequently sanded so that its upper surface **176** is flush with an upper surface **178** of back skin **166**, shown in FIG. **51**. The resulting exposed surface is essentially a lower one-half of each metallic pin **143**, which is electrically coupling each of the radiating elements **140** on opposite sides of the wall section **138***a* or **138***b*. Thus, metallic pins **143** essentially form electrical contact "pads" which readily enable electrical coupling of external components to the antenna aperture **10**.

In mobile platform applications, the antenna aperture **10** also allows the integration of antenna or sensor capabilities without negatively impacting the aerodynamic performance of the mobile platform. The manufacturing method allows apertures of widely varying shapes and sizes to be manufactured as needed to suit specific applications.

Construction of Antenna Aperture Having Conformal Radome

Referring to FIG. **52**, a multi-faceted, conformal, phased-array antenna system **200** is shown in accordance with an alternative embodiment. Antenna system **200** generally includes a one-piece, continuous back skin **202** having a plurality of distinct, planar segments **202***a*, **202***b*, **202***c* and **202***d*. Four distinct antenna aperture sections **204***a*-**204***d* are secured to a front surface **205** of each of the back skin segments **202***a*-**202***d*. Antenna aperture sections **204***a*-**204***d* essentially form honeycomb-like core sections for the system **200**. A preferably one piece, continuous radome **206** covers all of the antenna aperture sections **204***a*-**204***d*. Although four distinct aperture sections are employed, a greater or lesser plurality of aperture sections could be employed. The system **200** thus has a sandwich construction with a plurality of honeycomb-like core sections that is readily able to be integrated into non-linear composite structures.

The conformal antenna system **200** is able to provide a large number of densely packed radiating elements in accordance with a desired mold line to even better enable the antenna system **200** to be integrated into a non-linear structure of a mobile platform, such as a wing, fuselage, door, etc. of an aircraft, spacecraft, or other mobile platform. While the antenna system **200** is especially well suited for applications involving mobile platforms, the ability to manufacture the antenna system **200** with a desired curvature allows the antenna system to be implemented in a wide variety of other applications (possibly even involving on fixed structures) where a stealth, aerodynamics and/or load bearing capability are important considerations for the given application.

Referring to FIG. **53**, the back skin **202** is shown in greater detail. The back skin **202** includes a plurality of openings **208** that will serve to connect with teeth of each of the antenna aperture sections **204***a*-**204***d*. By segmenting the back skin **202** into a plurality of planar segments **202***a*-**202***d*, printed circuit board assemblies can be easily attached to the back skin **202**. The back skin **202** may be constructed from Astroquartz® fibers or in accordance with the construction of the back skin **166** shown in FIG. **48**. The back skin **202** is precured to form a rigid structure that is supported on a tool **210** that is shaped in accordance with the contour of the back skin **202**.

Referring to FIG. **54**, the construction of antenna aperture section **204***a* is illustrated. The sections **204***a*-**204***d* could each be constructed with any of the construction techniques described in the present specification. Thus, the assembly of wall sections **212***a* and **212***b* onto the back skin **202** is intended merely to illustrate one suitable method of assembly. In this example, wall sections **212***a* and **212***b* are assembled using the construction techniques described in connection with FIGS. **31**-**37**. Teeth **214** of wall sections **212***a* are inserted into holes **208** to secure the wall sections **212***a* to the back skin **202**. Wall sections **212***b* having teeth **216** are then secured to the back skin **202** in interlocking fashion with wall sections **212***a*. During this process the entire back skin **202** is supported on the tool **210**. Each of the antenna aperture sections **204***a*-**204***d* are assembled in a manner shown in FIG. **54**.

Referring to FIG. **55**, one wall portion **212***a* is illustrated. Each of wall portions **212***a* of antenna module **204***a* have a height **218** that is at least as great, and preferably just slightly greater than, a height **220** of the highest point that the antenna aperture section **204***a* will have once the desired contour is formed for the antenna system **200**. A portion of the desired contour is indicated by dashed line **222**. Portion **224** above the dashed line **222** will be removed during a subsequent manufacturing operation, thus leaving only a portion of the wall section **212***a* lying beneath the dashed line **222**. For simplicity in manufacturing, it is intended that the wall sections **212***a* and **212***b* of each of antenna modules **204***a*-**204***d* will initially have the same overall height. However, depending upon the contour desired, it may be possible to form certain ones of the aperture sections **204***a*-**204***d* with an overall height that is slightly different to reduce the amount of wasted material that will be incurred during subsequent machining of the wall portions to form the desired contour.

Referring to FIG. **56**, once all of the aperture sections **204***a*-**204***d* are assembled onto the back skin, then beads of adhesive **219** are placed at the intersecting areas of each of the wall portions **212***a* and **212***b*. Metallic blocks **40** are then inserted into the cells formed by the wall portions **212***a* and **212***b*.

Referring to FIG. **57**, metal plates **224***a*-**224***d* are then placed over each of the aperture sections **204***a*-**204***d*. The entire assembly is covered with a vacuum bag **226** and rests on a suitably shaped tool **228**. The assembly is vacuum compacted and then allowed to cure in an oven or autoclave.

In FIG. **58**, the cured antenna aperture sections **204***a*-**204***d* and back skin **202** are illustrated after the metallic blocks **40** have been removed. Dashed line **230** indicates a contour line that an upper edge surface of the aperture sections **204***a*-**204***d* are then machined along to produce the desired contour.

Referring to FIG. **59**, the one piece, pre-cured radome **206** is then aligned over the aperture sections **204***a*-**204***d* and bonded thereto during subsequent compaction and curing steps using tool **210**. Surface **212'** now has the contour that is needed to match the mold line of the structure into which the antenna system **200** will be installed.

With reference to FIGS. **60** and **61**, the construction of one antenna electronics circuit board **232***a* is shown in greater detail. In FIG. **60**, circuit board **232***a* includes a substrate **236** upon which an adhesive film **238** is applied. The adhesive film **238** may comprise one ply of 0.0025" (0.0635 mm) thick, Structural™ bonding tape available from 3M Corp., or possibly even a plurality of beads of suitable epoxy. If adhesive film **238** is employed, a plurality of circular or elliptical openings **240** are produced by removing portions of the adhesive film **238**. The openings **240** are preferably formed by punching out an elliptical or circular portion after the adhesive film **238** has been applied to the substrate **236**. The openings **240** are aligned with the teeth **214** and **216** of each of the wall sections **212***a* and **212***b*. The thickness of adhesive film **238** may vary but is preferably about 0.0025 inch (0.0635 mm)

In FIG. **61**, a syringe **242** or other suitable tool is used to fill the holes **240** with an electrically conductive epoxy **244**. The electrically conductive epoxy **244** provides an electrical coupling between the teeth **214** and **216** on each of the wall sections **212***a* and **212***b* and circuit traces (not shown) on circuit board **232***a*.

The bonded and cured assembly of FIG. **59** is then bonded to the circuit boards **232***a*-**232***d*. A suitable tooling jig with alignment pins is used to precisely locate the circuit boards **232***a*-**232***d* with the teeth **214** and **26** of each of the aperture sections **204***a*-**204***d*. The assembled components are placed on a heated press. Curing is performed at a temperature of preferably about 225° F.-250° F. (107° C.-131° C.) at a pressure of about 20 psi minimum for about 90 minutes.

Referring to FIG. **62**, depending upon the degree of curvature that the contour at the antenna system **200** needs to meet, the small areas inbetween adjacent antenna modules **204***a*-**204***d* may be too large for the load bearing requirements that the antenna system **200** is required to meet. In this event, the wall portions **212***a* and **212***b* can be pre-formed with a desired shape intended to reduce the size of the gaps formed between the aperture sections **204***a*-**204***d*. An example of this is shown in FIG. **62** in which three aperture sections **252***a*, **252***b* and **252***c* will be required to form a more significant curvature than illustrated in FIG. **52**. In this instance, wall sections **254***a* of each aperture section **252***a*-**252***c* are formed such that the edge that is adjacent center module **252***b* significantly reduces the gaps **256** that are present on opposite sides of antenna module **252**. In practice, the wall sections **212***a* and/or **212***b* can also be formed with dissimilar edge contours to reduce the area of the gaps that would otherwise be present between the edges of adjacent aperture sections **204***a*-**204***d*.

By forming a plurality of distinct aperture sections, modular antenna systems of widely varying scales and shapes can be constructed to meet the needs of specific applications.

Further Alternative Construction of Antenna Aperture

Further embodiments of antenna apertures and methods of forming the same will be explained with reference to FIGS. **63**-**70**. In some embodiments construction of an antenna aperture is enhanced by the use of novel adhesive components and tools, and associated construction techniques. Referring briefly to FIGS. **63**-**65**, in one embodiment construction of an antenna aperture is enhanced by the use of at least one film adhesive assembly comprising a layer of adhesive film **315** and a plurality of adhesive packs **320**. In one embodiment the adhesive packs **320** are spaced on the adhesive film **315** in a manner that corresponds to the dimensions of the individual cells of the antenna aperture **10**. The adhesive packs **320** may be formed from an outer layer that comprises an adhesive film (which may be contiguous with adhesive film **315**) or a polymeric coating, and may comprise an adhesive paste. The adhesive film **315** may be mounted on a back skin **310**, which may correspond to the back skin **16** depicted in FIG. **1**.

Adhesive film **315** may further comprise a plurality of rebates **330** formed in a predetermined pattern. In one embodiment, the predetermine pattern corresponds to a pattern of antenna feed elements on an electronics board **232** (FIGS. **59**-**62**) which may be mounted to the back skin **315**. In such embodiments, back skin **310** may comprise corresponding via holes to allow for electrical interconnection between circuit elements **340** on the electronics board **232** and electrical components **14** on the antenna aperture **10**.

In the embodiment depicted in FIG. **63** the adhesive film **315** comprises a matrix of evenly spaced adhesive packs **320**, each of which is surrounded by four rebates **330**. This configuration permits the radiating elements **14** (FIG. **6**) on each of the four sides of each antenna aperture **10** to establish electrical contact with an electronics board **232**. One skilled in the art will recognize that other configurations may be used.

FIG. **65** is a close-up illustration of a section of a rebate **330** in the adhesive assembly covering the backskin **315**. Referring to FIG. **65**, in some embodiments one or more of the rebates may be formed by using a laser to ablate sections of the film adhesive **315** to define the rebate **330**. One skilled in the art will recognize that other removal operations may be used. In some embodiments a small dam **332** surrounding a connection point which provides an electrical connection to an electrical feed (e.g., an RF feed) **340** on the electronics board **232** may be formed on the electronics board **232**. In some embodiments the dam **332** may be formed by a liquid photoimaging (LPI) process or the like. Heat from the laser cures the adhesive around the rebate, which acts as a dam **332** on the adhesive.

In some embodiments construction of an antenna aperture **10** may be enhanced by using an adhesive film assembly like that depicted in FIGS. **63**-**65**.

FIG. **66** is a flowchart illustrating operations in a method to make an antenna aperture **10**, according to embodiments. Referring to FIG. **66**, at operation **410** a honeycomb core structure of the antenna aperture **10** is formed using one or more of the techniques described herein. As used herein, the term honeycomb core structure refers to the assembly formed by the respective wall sections **12**. By way of example, the sub assembly **76** depicted in FIG. **24** may be considered a honeycomb core structure, as used herein. Further, while the embodiments described herein illustrate a honeycomb core structure **76** which is formed from a plurality of wall structures **14** disposed substantially at right angles, it will be appreciated that other configurations may be used.

At operation **415** a first adhesive film **315** is positioned on a back skin **310**. As described above, in some embodiments the rebates **330** in the adhesive film **315** may align with vias on the backskin **310**. At operation **420** the back skin **310** is positioned on the honeycomb core structure **76**. In one embodiment the lower surfaces of the wall sections **12** define a first surface and the upper surfaces of the wall sections **12** define a second surface. More accurately, the respective upper and lower surfaces of the wall sections **12** define a plurality of surfaces. These plurality of surfaces may be referred to collectively herein as a surface. Thus, in one embodiment operation **420** may be implemented by positioning the back skin **310** on the lower surface of the honeycomb core structure **76** such that the adhesive packs **320** each reside in one of the cells defined by the wall structures **12**.

At operation **425** the honeycomb core structure **76** is filled with blocks **40** as described above with reference to FIG. **34**. In one embodiment, the blocks **40** may be formed from a material having a relatively high coefficient of thermal expansion (CTE), e.g., without limitation a Teflon material or the like. Using blocks **40** constructed from a high CTE material, permits the blocks **40** to be sufficiently undersized to facilitate easy insertion and extraction from the assembly **76**. The design and high CTE of the tooling blocks **40** reduces the amount of adhesive on the cell walls and allows for the adhesive **320** to ride up and create fillets along the intersections of the cell walls and core to backskin.

At operation **430** a second adhesive film **315** is positioned on a radome **112**, and at operation **435** the radome **112** is positioned on the second surface of the honeycomb core structure **76** defined by the upper surfaces of wall sections **12**. In some embodiments the second adhesive film **315** is laser ablated to allow for the adhesive to be matched and positioned on the assembly **76** and create fillets between the radome and core.

At operation **440** the entire assembly is compressed and at operation **445** the assembly is heated. Operations **440** and **445** may be performed as described above with reference to FIG. **35**, e.g., by placing the assembly in a vacuum bag **70** and curing the assembly in an autoclave. When the assembly is heated in the autoclave the pressure and temperature forces the adhesive in the adhesive packs **320** to cover the wall sections **12** of the cells **10**, thereby forming a structural fillet. In some embodiments the structural fillet is between the intersecting cell walls and also along the backskin to the cell wall.

In an alternate embodiment the tool blocks **40** may be replaced with a multi-part, honeycomb shaped tool **350** that may be inserted into the cells of the honeycomb structure **76** during the curing process, then removed to allow placement of the radome **112** on the assembly. FIGS. **67-69** are cross-sectional views of a tooling assembly and an antenna assembly, according to embodiments. Referring to FIGS. **67-69**, in one embodiment a first honeycomb tool **350** comprises a plurality of plugs **352** which are dimensioned to fit in the respective cells defined by the wall sections **12** of the honeycomb core structure **76**. In one embodiment the plugs **352** may be formed from a high CTE material, e.g., a silicone rubber material or the like.

A second honeycomb tool **360** further includes a plurality of plugs **362** dimensioned to fit in the plugs **352** of the first tool **350**. The tool **360** may be formed from a substantially rigid material having a relatively low CTE, e.g., aluminum, plastic or the like. In some embodiments, tool **360** comprises a top block **364**. One or more fluid tubes **366** extend through top block **364** and one or more fluid tubes **368** extend through the plugs **362**.

FIG. **70** is a flowchart illustrating operations in a method to make an antenna aperture **10** using the tool assembly depicted in FIGS. **67-69**. Referring to FIGS. **67-70**, at operation **510**, a honeycomb core structure **76** of the antenna aperture **10** is formed using one or more of the techniques described herein. As used herein, the term honeycomb core structure **76** refers to the assembly formed by the respective wall sections **12**. By way of example, the sub assembly **76** depicted in FIG. **24** may be considered a honeycomb core structure **76**, as used herein. Further, while the embodiments described herein illustrate a honeycomb core structure **76** which is formed from a plurality of wall structures disposed substantially at right angles, it will be appreciated that other configurations may be used.

At operation **515**, a first adhesive film **315** is positioned on a back skin **310**. As described above, in some embodiments the rebates **330** in the adhesive film **315** may align with vias on the back skin **310**. At operation **520**, the back skin **310** is positioned on the honeycomb core structure. In one embodiment, the lower surfaces of the wall sections **12** define a first surface and the upper surfaces of the wall sections **12** define a second surface. More accurately, the respective upper and lower surfaces of the wall sections **12** define a plurality of surfaces. These plurality of surfaces may be referred to collectively herein as a surface. Thus, in one embodiment, operation **520** may be implemented by positioning the back skin **310** on the lower surface of the honeycomb core structure **76** such that the adhesive packs **320** each reside in one of the cells defined by the wall structures **12**.

At operation **525**, the first honeycomb tool **350** is positioned in the honeycomb core structure **76**. As illustrated in FIG. **68**, the first honeycomb tool **350** is positioned such that the plugs **352** are in contact with adhesive packs **350**. At operation **530**, the second honeycomb tool **360** is positioned such that the plugs **362** of the second honeycomb tool **360** fit within the plugs **352** of the first honeycomb tool **350** (FIG. **69**).

The resulting assembly depicted in FIG. **69** may then be compressed (operation **535**) and heated (operation **540**) as described above to form an antenna aperture assembly like the assembly **114** depicted in FIG. **37**. When the assembly **114** is finished bonding, the tools **350** and **360** may be removed from the honeycomb structure **76**. In one embodiment, a pressurized fluid (e.g., air or the like) may be delivered through the fluid tubes **366**, **368** to facilitate removal of the tools **350**, **360** from the assembly. Subsequently, a radome **112** (FIG. **36**) may be secured to the upper surfaces of the wall sections **12** of the honeycomb structure **76**, as described above.

In an alternate embodiment, adhesive may be delivered under pressure through fluid tubes **366**, **368**. In such embodiments, the adhesive packs **320** may be omitted from the film assembly disposed on the back skin **310**.

Referring next to FIGS. **71** and **72**, embodiments of the disclosure may be used in the context of an aircraft manufacturing and service method as shown in FIG. **71** and an aircraft **276** as shown in FIG. **72**. Aircraft applications of the disclosed embodiments may include, for example, without limitation, composite stiffened members such as fuselage skins, wing skins, control surfaces, hatches, floor panels, door panels, access panels and empennages, to name a few. These materials may also find use in applications in gas turbine/rocket engine components such as compressor blades and disks, and gas turbine blades and disks, and ramjet/scramjet engine components. During pre-production, exemplary method may include specification and design **278** of the aircraft **276** and material procurement **280**. During production, component and subassembly manufacturing **282** and system integration **284** of the aircraft **276** takes place. Thereafter, the aircraft **276** may go through certification and delivery **286** in order to be placed in service **288**. While in service by a customer, the aircraft **276** is scheduled for routine maintenance and service **290** (which may also include modification, reconfiguration, refurbishment, and so on).

Each of the processes of method may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in FIG. **71**, the aircraft **276** produced by exemplary method may include an airframe **292** with a plurality of systems **294** and an interior **296**. Examples of high-level systems **294** include one or more of a propulsion system **298**, an electrical system **2100**, a hydraulic system **2102**, and an environmental system **2104**. Any number of other systems may be included. Although an aerospace example is shown, the principles of the invention may be applied to other industries, such as the automotive industry.

The apparatus embodied herein may be employed during any one or more of the stages of the production and service method **74**. For example, components or subassemblies corresponding to production process **82** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **76** is in service. Also, one or more apparatus embodiments may be utilized during the production stages **82** and **84**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **76**. Similarly, one or more apparatus embodiments may be utilized while the aircraft **76** is in service, for example and without limitation, to maintenance and service **90**.

Thus, described herein are novel methods to form a load bearing antenna aperture and novel structures resulting from such methods. The various methods provide an antenna aperture having a honeycomb-like core sandwiched between a pair of panels that forms a construction enabling the aperture to be readily integrated into composite structures to form a load bearing portion of the composite structure. The antenna apertures do not add significant weight beyond what would otherwise be present with conventional honeycomb-like core, sandwich-like construction techniques, and yet provides an antenna capability.

Reference in the specification to "one embodiment" or "some embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least an implementation. The appearances of the phrase "in one embodiment" in various places in the specification may or may not be all referring to the same embodiment.

What is claimed is:

1. A load bearing antenna aperture assembly, comprising:

a honeycomb core structure having a plurality of wall sections, the wall sections including electromagnetic radiating elements, and wherein lower surfaces of the wall sections defines a first surface and upper surfaces of the wall sections define a second surface;

a first adhesive pack disposed on the first surface, wherein the adhesive pack comprises:

a layer of adhesive film; and

a paste adhesive disposed on the layer of adhesive film;

a back skin disposed on to the first surface of the honeycomb core structure by the first adhesive pack;

an antenna electronics board disposed adjacent at least a portion of the back skin, wherein:

the antenna electronics board comprises a plurality of antenna feed elements arranged in a predetermined pattern; and

the first layer of adhesive film comprises a plurality of rebates formed in a predetermined pattern corresponding to the predetermined pattern of antenna feed elements.

2. The load bearing antenna aperture assembly of claim **1**, wherein the layer of adhesive film further comprises a plurality of adhesive dam structures in a predetermined pattern corresponding to the predetermined pattern of antenna feed elements.

3. The load bearing antenna aperture assembly of claim **1**, further a second adhesive pack positioned on the second surface, wherein the second adhesive pack comprises:

a first layer of adhesive film;

a second layer opposite the first layer of adhesive film; and

a paste adhesive disposed between the first layer and the second layer.

4. An apparatus comprising:

a core having a plurality of walls defining a number of cells, the cells comprising radiating elements of an antenna, and the core defining a surface;

a layer of film positioned on the surface of the core; and

a plurality of adhesive packs positioned on the layer of film, the adhesive packs providing connections to the radiating elements and an electronics board of the antenna; and

a plurality of rebates, the rebates patterned to correspond to antenna feed elements on the electronics board.

5. The apparatus of claim **4**, wherein the plurality of adhesive packs are evenly spaced in a matrix, and individual rebates are positioned around an individual adhesive pack.

6. The apparatus of claim **4**, wherein an individual rebate is formed in an ablated portion of the adhesive skin.

7. The apparatus of claim **4**, wherein an individual rebate comprises a dam surrounding a connection point to an electrical feed on the electronics board.

8. The apparatus of claim **4**, wherein at least four rebates surround an adhesive pack, and connections from each of the four rebates for an individual adhesive pack are connected to each of four walls for an individual cell.

9. The apparatus of claim **4** further comprising a backskin positioned on the surface of the core and the adhesive layer is positioned on the backskin, the backskin having a number of via holes and connections between the radiating elements and the electronics board passing through the via holes.

10. The apparatus of claim **4**, wherein the adhesive packs comprise an adhesive paste.

11. An antenna comprising;

a plurality of walls comprising a core structure having a number of cells, the plurality of walls comprising radiating elements of the antenna, the core structure defining a first surface;

a backskin positioned on the first surface of the core, wherein the backskin comprises a number of via holes;

a layer of film positioned on the backskin such that the layer of film faces the first surface of the core;

a circuit board positioned proximate the backskin;

a plurality of rebates, the plurality of rebates patterned to correspond to antenna feed elements on the circuit board, connections between the radiating elements of the antenna and the circuit board provided through the via holes; and

a plurality of adhesive packs positioned on the layer of film, the adhesive packs providing connections to the radiating elements and the circuit board.

12. The antenna of claim **11**, wherein the plurality of adhesive packs is spaced so as to correspond to a dimension of the individual cells.

13. The antenna of claim **11**, wherein the plurality of adhesive packs are evenly spaced in a matrix, and individual rebates surround an individual adhesive pack, an individual adhesive pack of the plurality of adhesive packs positioned within a corresponding individual cell.

14. The antenna of claim **13**, wherein an individual rebate comprises a dam surrounding a connection point to an electrical feed on the circuit board.

15. The antenna of claim **11**, wherein the core comprises a second surface, a radome positioned on the second surface such that the core structurally supports the radome.

16. The antenna of claim **11**, wherein the core defines a second surface, the second surface corresponding to a curvature of a mold line of an aircraft.

17. A load bearing antenna aperture comprising:

a plurality of wall elements comprising a core structure having a number of cells, the plurality of wall elements including radiating elements of the antenna, the core structure defining a first surface and a second surface;

a backskin positioned on the first surface of the core;

a layer of film positioned on the backskin facing the core structure;

a circuit board positioned on the backskin facing away from the core structure;

a plurality of adhesive packs positioned on the layer of film, the plurality of adhesive packs spaced so as to correspond to a dimension of the individual cells, the adhesive packs providing connections to the radiating elements and the circuit board;

a plurality of rebates, a set of individual rebates positioned around an individual adhesive pack; and

a load supported on the second surface of the core.

18. The load bearing antenna of claim **17**, wherein four rebates surround an individual adhesive pack and each of the four rebates is connected to one of four walls of the cell proximate the adhesive pack.

19. The load bearing antenna of claim **17**, wherein wall portions of the second surface define a curvature corresponding to a mold line of an aircraft.

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